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AUGUST 1949

UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
JAMES BOYD, DIRECTOR

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ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL FISCAL YEAR 1948

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A. C. FIELDNER AND SIDNEY GOTTLIEB

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL FISCAL YEAR 1948[1]

By A. C. Fieldner[2] and Sidney Gottlieb[3]

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INTRODUCTION

This report summarizes the research and technologic work of the Bureau of Mines on coal and coal products from July 1, 1947, to July 1, 1948. It is the thirteenth of a series presenting résumes based largely upon publications issued during the year. In some instances, research and testing results, not otherwise available in published form, are presented. The individual publications given as footnote references herein will provide further detail to the interested reader.

The period covered by this report was marked by an ever-mounting concern for the adequacy of the Nation's fuel resources and for fuel shortages arising from an increasing demand for fuels at home and abroad. Several reports appeared which delineated the place of synthetic liquid fuels in the future fuel technology and economy of the Nation, emphasized the fact that eventually the principal raw material for the production of such fuels will be[4, 5, 6] coal, and described the

4/ Fieldner, A. C., Synthetic Liquid Fuels from Coal and Oil-Shale: Ohio State University Engineering Experiment Station News, vol. 20, No. 1, 1948, pp. 22-28.

5/ Schroeder, W. C., Synthetic Liquid Fuels in the United States: Mech. Eng., vol. 69, No. 2, December 1947, pp. 989-995.

6/ Schroeder, W. C., Comparison of Major Processes for Synthetic Liquid Fuels: Chem. Ind., vol. 62, No. 4, 1948, pp.

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progress made by the Bureau of Mines in developing processes for the production of synthetic liquid fuels. Congressional committees[7, 8, 9] heard testimony along similar lines.

Increased awareness of the fuels problems confronting the Nation led to an authorization by the 80th Congress for the erection of an anthracite research laboratory at Schuylkill Haven, Pa., to house expanded Bureau of Mines research on anthracite. Design of the structure was well under way by the end of the fiscal year. (See fig. 1.) Looking forward to expansion of Bureau research on lignite, the 80th Congress heard testimony on the problems and programs of lignite research[10, 11] as a prelude to authorizing the construction of a lignite research laboratory in North Dakota.

SUMMARY

As peacetime demands for coal continued at peak levels and the coal industry successfully increased production to meet that demand, additional emphasis was placed on the Bureau of Mines research program of increased efficiency, conservation, and safety in the mining, preparation, and utilization of coal.

Implementing the conservation in utilization of coal phase of this program, the Bureau rendered service to Federal agencies that involved consultations on the purchase of fuel and fuel-burning equipment, testing fuels and boiler-room equipment, analyzing boiler water, recommendations on boiler-water chemical treatment, supplying boiler-water test kits, and sampling and analyzing coal. These services

7/ Schroeder, W. C., Statement on Synthetic Liquid Fuels, Hearing before the House of Representatives Committee on Interstate and Foreign Commerce: 80th Cong., 2d Sess., Mar. 4 and 5, 1948, U. S. Govt. Printing Office, Washington, D. C., 1948, pp. 8-36.

8/ Schroeder, W. C., Statement on Synthetic Liquid Fuels, Hearings before the House of Representatives Special Subcommittee on Petroleum of the Committee on Armed Services: 80th Cong., 2d Sess., Feb. 23, 1948, U. S. Govt. Printing Office, Washington, D. C., 1948, pp. 616-637.

9/ Schroeder, W. C., Statement on Synthetic Liquid Fuels published in Hearings before the Subcommittee on Mines and Mining of the Committee on Public Lands, House of Representatives: 80th Cong., 1st Sess., on H. R. 2161. Demonstration Plants to Produce Synthetic Liquid Fuels: Committee Print 14, U. S. Govt. Printing Office, Washington, D. C., June 9, 1947, pp. 2-4.

10/ Fieldner, A. C., Statement on the Establishment of a Research Laboratory in the North Dakota Lignite-Consuming Region: Hearing before a Subcommittee of Senate Committee on Interior and Insular Affairs, 80th Cong., 2d Sess., Feb. 19, 1948, U. S. Govt. Printing Office, Washington, D. C., 1948, pp. 16-18. Statement on same subject, Hearings before Subcommittee on Mines and Mining of the Committee on Public Lands: House of Representatives, 80th Cong., 1st Sess., Committee Print 14, U. S. Govt. Printing Office, Washington, D. C., June 7, 1947, pp. 24-26.

11/ McCabe, L. C., Statement on the Establishment of a Research Laboratory in the North Dakota Lignite-Consuming Region: Hearings before Subcommittee on Mines and Mining of the Committee on Public Lands, House of Representatives, 80th Cong., 1st Sess., June 27, 1947, Committee Print 14, U. S. Govt. Printing Office, Washington, D. C., pp. 32-33.

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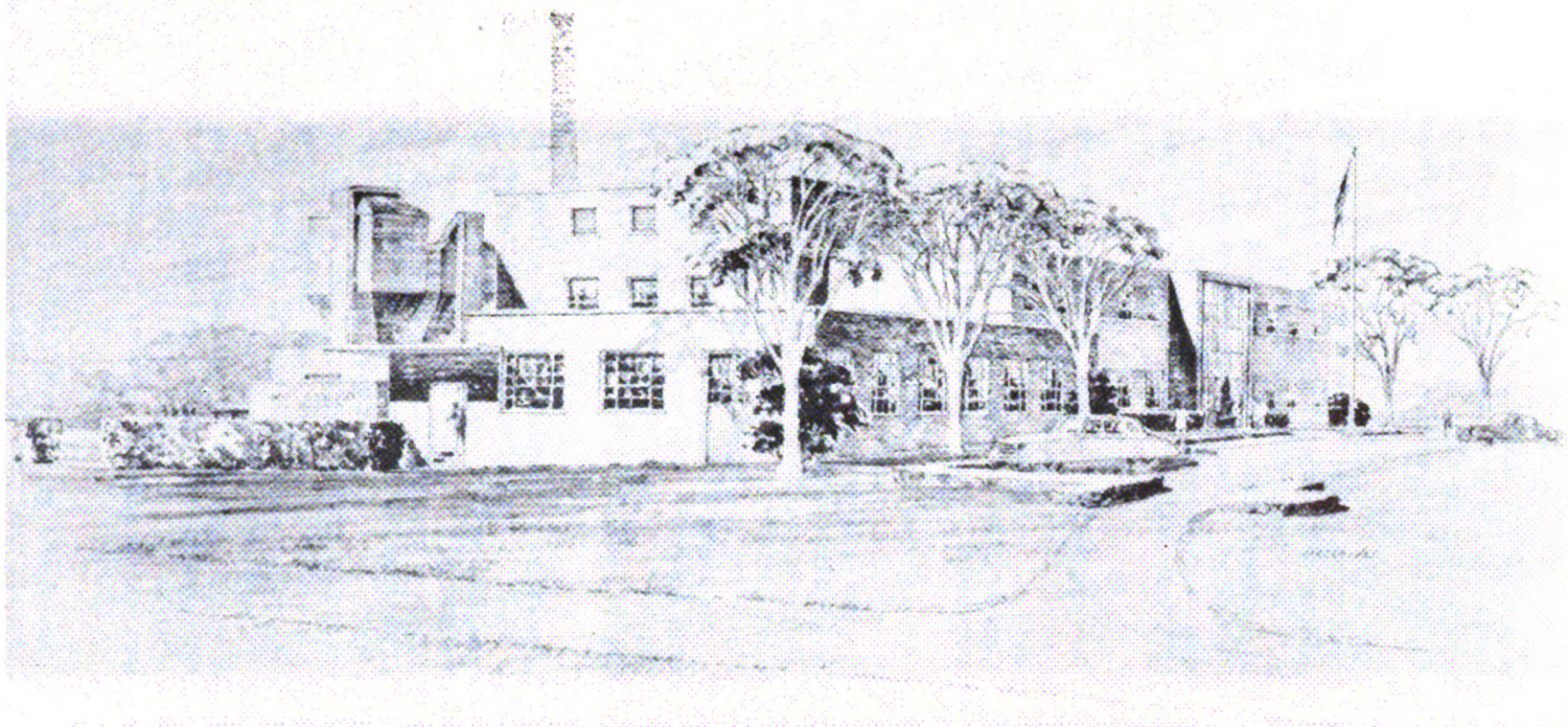

Figure 1. - Anthracite Research Laboratory, Schuylkill Haven, Pa.

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required the analysis of 6,841 coal samples. In addition, 6,334 samples of coal and coal products were analyzed in the course of Bureau of Mines research and test work on mining, preparation, and utilization of coal. To assist Federal coal-mine inspectors in making safety recommendations at the larger coal mines, 9,485 coal-dust samples were analyzed.

Various investigations of coal deposits by core drilling to provide supplies of coal in fuel-short areas and to augment our depleted deposits of coking coal were continued. In Washington, a reserve of over 8 million tons of lignite was proved of which 5,300,000 are considered minable by stripping methods. In Oregon, drilling proved 13,600,000 tons of minable reserves of coal. In Rhode Island drilling demonstrated the lack of continuity of the meta-anthracite deposits. Investigations of deposits in Colorado, Maryland, North Carolina, and Alaska were continued.

The Bureau-designed scraper-shaker loader for mechanical mining of anthracite was improved by further modification. As the effectiveness of special shearing machines had been proved, plans were made to use these machines in establishing mechanical mining systems for removing thick bed pillars in anthracite, a project that may permit recovery of millions of tons of coal now lost underground.

The possibility of removing noxious aldehydes from the exhaust of Diesel engines underground by scrubbing was demonstrated, and 55 approvals for various items of electrical equipment for use underground in coal mines were given. Two-way radio communication was shown to be satisfactory for use underground, and various safety practices in coal mines were investigated and either recommended or disapproved. It was shown that rock dusting would prevent dust explosions in underground workings when carried to within 40 feet of the working face and that a minimum of 65 percent incombustible matter must be maintained in the dust. The Bureau carried out over 1,600 tests on permissible explosives and blasting devices, types of explosives, detonators, and hazardous explosives, and the list of permissible explosives was increased to 191. A satisfactory permissible multiple-shot blasting unit was developed.

Increasing mechanization of coal mining and the necessity of substituting lower-grade coals have placed added emphasis on preparation as a means of providing suitable coal supplies. Research in this field resulted in the development of a new cleaning and dewatering process for fine-size coal and in further refinement of the cyclone washer for cleaning fine coal and clarifying washery water. The efficacy of washing in beneficiating coking coals as a means of offsetting depletion of these valuable coals was demonstrated on Maryland coal beds, and a fundamental study of the forms of sulfur in bituminous coal promises aid in solving the problem of providing adequate supplies of metallurgical coal so essential to our national security and peacetime economy. Conservation of our dwindling supplies of high-rank coal requires that means be devised to utilize our low-rank coals. To this end, Bureau research went forward on the development of a flash-drying process for subbituminous coal which has considerable promise for the efficient removal of moisture. The study of storage of low-rank coals provided valuable data that will be used in studying the storage of millions of tons of lignite being excavated from a dam site in North Dakota.

Fuel-engineering service to Government establishments by the Bureau of Mines resulted in marked operational savings, particularly at Army and veterans' hospital installations. Valuable information obtained in the course of experience with

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Government plants was disseminated to industry as an aid toward increasing the efficiency of fuel utilization throughout the country.

During the fiscal year, analyses and recommendations were made on 8,180 samples of boiler water from various Government boiler plants. Research on the treatment of boiler water has resulted in developments that will reduce the cost of treatment. Chemicals and methods for controlling intracrystalline cracking in boilers were developed.

Techniques were developed for determining the temperature and composition of gases in pulverized-coal-fired furnaces, an important contribution to conservation, since it improves the thermal efficiency of coal combustion and increases our ability to burn a wide range of grades of coal.

As part of its program of augmenting our depleted reserves of coking coal, the Bureau of Mines obtained complete data on the carbonizing properties of two West Virginia coals and one each from Kentucky and Mexico. Additional tests were made on 47 other coking coals or blends of coking and noncoking coals. Particular attention was paid to the swelling properties of coal during the coking process, and the plasticity of coals and oxidation of coal were shown to have a deleterious effect upon carbonizing properties of many coals. Investigation of the production of gas and char by gasification of lignite in an externally heated alloy retort was continued, and it was demonstrated that such methods can operate at high thermal efficiencies.

Several publications on coal mining and technology in Europe and particularly in Germany have provided data heretofore unavailable.

Continuing its investigation of the feasibility of exploiting coal deposits through gasification underground, Bureau of Mines investigators devised a laboratory-scale retort that has provided experimental data on the factors involved. Preparations were made to conduct a second field-scale gasification experiment at Gorgas, Ala., in cooperation with the Alabama Power Co.

The Bureau of Mines program on the production of synthetic liquid fuels from coal continued during the year with marked success. Laboratory research and pilot-plant experimentation on the production of synthesis gas and on the synthesis of liquid fuels from such gas progressed sufficiently to permit design of an 80- to 100-barrel-per-day Demonstration Plant at Louisiana, Mo., and construction of the plant was in its initial stages at the end of the fiscal year. With the construction of the 200- to 300-barrel-per-day Coal-Hydrogenation Demonstration Plant at Louisiana, Mo., over 80 percent complete, laboratory research designed to meet problems which may be encountered during operation of the plant was continued. New laboratories to house synthetic liquid fuels research were completed at Bruceton, Pa. (See fig. 2.)

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Figure 2. - Air view of synthetic liquid fuels laboratories and pilot plants at Bruceton, Pa.

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University of Alabama
University of Washington
University of West Virginia

ORIGIN, COMPOSITION, AND PROPERTIES OF COAL

Inspection, Sampling, and Analysis

Demand for coal for domestic use and export exceeded supply during the year, and the better grades were difficult to obtain. With some exceptions, Government agencies were able to obtain bids on their coal requirements, although in many instances coal of the desired quality was not offered. Coal was purchased on a guaranteed analysis basis, including penalties for delivery of substandard coal, by the Bureau of Prisons, U. S. Department of Justice, Office of Indian Affairs, U. S. Department of the Interior, War Department in scattered areas, and for export. Some purchases were made at a fixed price, subject to adjustment by negotiation for delivery of substandard coal, and other purchases were made at a fixed price not subject to adjustment for quality. Coal requirements of Federal agencies for the fiscal year were estimated at approximately 5,145,000 tons. The Navy Department purchased coal for both the Army and Navy and was by far the largest Federal purchasing agency for coal. Recommendations were made for awards of contracts for some agencies, and other agencies were furnished analyses to evaluate coal bids and substitute coals offered.

Upon the request of the War and Navy Departments, a program for the inspection and sampling of coal exported to the occupied countries was begun in April. The coal was purchased on a guaranteed analysis basis with penalties for delivery of substandard coal. To the end of the fiscal year about 120,000 tons had been inspected and sampled.

For the use of various Government agencies in making coal purchases and for public information, 424 tipple and face samples were collected at 154 mines in 8

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States. for research on carbonization, grindability, free swelling, and other properties of coal, 262 samples were collected in 185 mines.

Proximate or ultimate analyses were made of 4,298 samples, and fusing-temperature determinations were made on 2,119 samples in connection with Government purchases, tipple and breaker inspections, and coal exported to Japan and Europe. Two-thirds of the samples were analyzed for the War and Navy Departments and the remainder for other Government departments and agencies.

Research and test work by the Bureau of Mines relating to mining, preparation, and utilization of coal and coal products required analyses of 5,739 samples. Analyses were made of 605 samples of marine sediments submitted by the Geological Survey which were obtained from drill cores taken from the floor of the Gulf of Mexico.

Analyses were made of 9,485 samples of road, roof, rib, and gob dusts from approximately 1,500 coal mines in 18 States. These analyses were made to assist Federal coal-mine inspectors in determining whether corrective recommendations were necessary at specific mines and in formulating the recommendations where required.

Analyses of Michigan, North Dakota, South Dakota, and Texas Coals

The analyses of coals from four States - Michigan, North Dakota, South Dakota, and Texas - have been published in a technical paper[12/] as another in a series describing coals of various States. The geology of the coal fields, methods of mining, production, distribution, uses, and the relationship of mine samples to commercial shipments were discussed. Descriptions of tipple, face, and delivered samples included chemical analyses, calorific values, classification by rank, agglomerating index, and fusibility of ash temperatures. Descriptions were given of the location, thickness of bed, nature of floor and roof, and partings. Maps showing the areas known to contain coal were included.

Analyses of Miscellaneous Materials

Chemical analyses to aid in various investigations of the Bureau concerning coal utilization and safety in mines required tests of 123 samples of miscellaneous materials.

These included complete analyses of 20 boiler scales or water-formed deposits and of 7 boiler compounds to assist in formulating recommendations for feed-water treatments at various Government-agency steam plants. Two external deposits from boiler tubes were examined and the presence of boron as the equivalent of 11.8 percent B_2O_3, in one of the deposits was confirmed.

As part of an investigation of materials, available in coal fields, that are suitable for rock-dusting coal mines, 30 samples submitted by rock-dust producers and mine operators were examined. Tests of limestones from five deposits in four coal-mining States proved them to be suitable for use as rock dust in preventing coal-dust explosions. Thirteen samples of various substitutes for limestone dust

12/ Fieldner, A. C., Huddle, J. W., Andrews, D. A., Toenges, A. L., Bell, C. H., Anderson, R. L., Snyder, N. H., Cooper, H. M., Abernethy, R. F., and Tarpley, E. C., Analyses of Michigan, North Dakota, South Dakota, and Texas Coals: Bureau of Mines Tech. Paper 700, 1948, 106 pp.

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were rejected because they failed to meet rock-dusting requirements. These samples included disintegrated slag, spent bentonite, calcium carbide residue, trap rock, and fly ash from boiler furnaces.

Fusain determination by a chemical oxidation method on two coals from the Palau No. 5 mine, Coahuila, Mexico, and from the Upper Elkhorn No. 3 bed, Knott County, Ky., showed moderate amounts of 1.7 percent fusain in the Mexican coal and 2.5 percent in the Kentucky coal.

Analyses of four soot-remover compounds showed that they contained 70 to 90 percent sodium chloride. Three of the samples contained zinc, and one sample contained 20 percent of copper chloride.

Chemical analyses of the 58 other miscellaneous materials were made in connection with investigations of complete gasification, coke production, coal hydrogenation, coal combustion, and mine accidents.

Constitution, Properties, and Analytical Methods

Extractable Waxes from Lignitic and Subbituminous Coals of the United States

Investigation of the possible extraction of montan wax, similar to that extracted commercially from certain European brown coals, from low-rank coals of the United States was continued during the year. As preliminary tests had indicated that Arkansas lignites might be a potential source of this wax, a survey was made of representative lignites of this State. Thirteen channel samples, collected by the Bureau of Mines and the Geology Division of the Arkansas Resources and Development Commission from 10 outcrop exposures and abandoned strip mines in Clay, Dallas, Hot Spring, Ouachita, Poinsett, and Saline Counties, were examined. The coals from these sources occur in the Wilcox formation and are classified as attrital lignites.

The yields of wax were determined by solvent extraction, using benzene and a benzene-alcohol mixture, the solvents reported to have been used in commercial extraction of German brown coal. Low yields of wax were obtained from two bench samples of Dallas County lignite which had very high ash contents and from the Clay County sample. The yields of wax from the other sources ranged from 5.7 to 11.1 and 9.6 to 16.4 percent on an air-dried-lignite basis, using benzene and benzene-alcohol, respectively, as solvent.

Tests of the chemical and physical properties of the benzene extracts showed that they are similar in many respects to the Riebeck brand of crude montan wax formerly imported in large amounts from Germany. Probably the most significant difference is the greater "resin" content of the wax from the Arkansas samples. In this respect they more closely resemble a commercial grade of montan wax imported from Czechoslovakia. The benzene-alcohol extracts had higher acid and saponification values than the benzene extracts and when heated appeared only to soften rather than completely fuse.

Petrographic analyses were made of column samples of lignite from Arkansas, Texas, and North Dakota in connection with an investigation of montan wax in American lignite. The results of the thin-section study showed that lignites giving relatively high yields of extractable wax were attrital in composition, and the low-yield lignites were mainly composed of woody tissue. The Arkansas lignites examined were typically attrital and resembled some of the German brown coal in

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petrographic composition. The Texas and North Dakota lignites examined were xyloid (chiefly of woody tissue), with considerably less yellow translucent attritus than the bright attrital lignite from Arkansas.

Electron-Diffraction and Electron-Microscope Studies of Fischer-Tropsch Catalysts

Electron-diffraction techniques were utilized to determine the effective surface compounds in catalysts for the Fischer-Tropsch synthesis. X-ray diffraction methods are of value in revealing the nature of the bulk of the catalyst material, but they may not detect changes that take place at or near the surface of the catalyst. Electron diffraction is better-adapted to analyzing these surface compounds because electrons, not being as highly penetrating as X-rays, are diffracted in the surface layers.

One of the most widely held theories of the mechanism of the Fischer-Tropsch synthesis postulates that a carbide of the iron or cobalt catalyst is formed and that this compound is the effective catalytic agent. X-ray diffraction studies by the Bureau of Mines have indicated that cobalt carbide is not a factor in the synthesis on cobalt catalysts. Electron-diffraction results supported this finding. Patterns of cobalt carbide were readily obtained with intentionally carbided catalysts but not with those used in the synthesis. These showed patterns that are probably largely that of cobalt oxide (CoO), with possibly some metallic cobalt. Figure 3A, shows this type of pattern.

With iron catalysts, X-ray studies have shown indications of iron carbide in used catalysts, but electron-diffraction patterns have not shown the carbide. Nearly every used iron catalyst analyzed has shown a strong pattern of magnetite, Fe_3O_4, as illustrated in figure 3B. Thus, although not as yet conclusive, electron-diffraction evidence shows that oxides of iron and cobalt rather than carbides are the effective catalytic compounds.

Electron-microscope studies of Fischer-Tropsch catalysts[13] revealed the effects of the presence in catalysts of promoters, such as magnesia and thoria, and of carriers, like kieselguhr, in inhibiting the sintering of cobalt on reduction, thus preserving a large proportion of the surface area upon which the catalytic activity is so dependent. Much smaller particle size of the cobalt results when the reduction is carried out in the presence of the promoters thoria and magnesia. Addition of a kieselguhr carrier also decreases the size of the cobalt particles. Measurements of the average particle sizes showed: Cobalt basic carbonate, 0.01 micron; reduced cobalt basic carbonate, 0.22 micron; reduced carbonate and promoters, 0.011 micron; reduced carbonate and kieselguhr, 0.028 micron. Surface-area measurements by a nitrogen-adsorption method confirm this beneficial behavior of promoters and kieselguhr.

A peculiar crystalline aggregation occurred in cobalt-metal powder reduced from cobaltous oxide used in Fischer-Tropsch catalysts.[14] The oxide particles sintered into larger smooth droplets of cobalt that were aggregated into thin, hexagonal platelets. The hexagons vary in diameter from 7 to 25 microns, and their thickness

13/ Anderson, Robert B., McCartney, James T., Hall, W. Keith, and Hofer, L. J. E., Kieselguhrs. Suitability as Carriers in Catalysts: Ind. Eng. Chem., vol. 39, 1947, pp. 1618-1628.

14/ McCartney, J. T., and Anderson, R. B., Crystalline Aggregation of Cobalt Powder: Jour. Appl. Phys., vol. 18, 1947, pp. 902-903.

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is apparently of the order of the diameter of the component particles. X-ray diffraction analysis also shows that the crystal phase present is hexagonal cobalt. These hexagonal aggregates may be formed by forces similar to those operating in normal crystal formation, but since the component particles do not lose their identity and the aggregates are easily fractured, they can hardly be classed as true crystals.

Electron-Microscope Studies of a Micro-Organism Occurring in Acid Mine Drainage

Research groups working on the problem of acid mine drainage and its contribution to stream polution have devoted considerable attention to the role of bacteria in the formation of acid waters. Evidence has been given in the literature that an unidentified micro-organism appears to influence the oxidation of ferrous salts to less soluble ferric compounds that cause the objectionable rusty color of mine drainage and add to its acid content. Bureau of Mines electron-microscope studies have shown some interesting features of this micro-organism. Figure 4 is an electron micrograph of a pure culture of this bacterium. Figure 5 illustrates an apparent micro-organism that has been observed in natural and synthetic mine waters. The lower oval body in figure 4, displaying a dense nucleus or inclusion, is the common type found in the pure culture. At the top of figure 4 there is an apparent splitting of this organism or possibly a union of two, with disintegration of opposite rounded ends. Comparison of figures 4 and 5 indicates that this evolution probably results in the peculiar shape of the micro-organism found in mine drainage.

Petrographic Studies of Coal

Petrographic examinations were made of 627 feet of coal cores, and on the basis of the findings the coal was selectively sampled for special chemical and physical tests. The cores were recovered from the Bureau of Mines drilling projects in the Castleman Basin, Md., and at Eska, Alaska, and from the Bureau of Reclamation's drilling project at Moorhead Dam in the Powder River field, Wyo. Detailed strip logs were prepared of all cores studied to aid in field correlation of coal beds encountered in the test drilling.

A complete petrographic analysis by thin section study was made of a column sample of coal from the Fairview bed, Soot Creek mine, St. Clair County, Ala. The results of this analysis, showing the amounts of various components and types of coal, are presented in graphic form in figure 6. The same type of analysis was made of a drill-core sample of Fairview coal recovered from a test drill hole 1-1/2 miles from the Soot Creek mine. A comparison of the amounts of coal components determined in the analyses of the coal core and column sample is shown in table 1. This table shows a fusain content for the column sample almost double that of the coal core from the drill hole. The large difference in fusain content determined for two coal samples from the same coal bed is explained by the fact that the coal core recovered from the drill hole was in a badly broken condition, and much of the soft fusain had been pulverized to dust and lost in recovering and handling the core. The lower part of the table shows the coal components of the two samples recalculated on a fusain free basis and the results here indicate essentially the same petrographic composition for the Fairview coal at the two localities.

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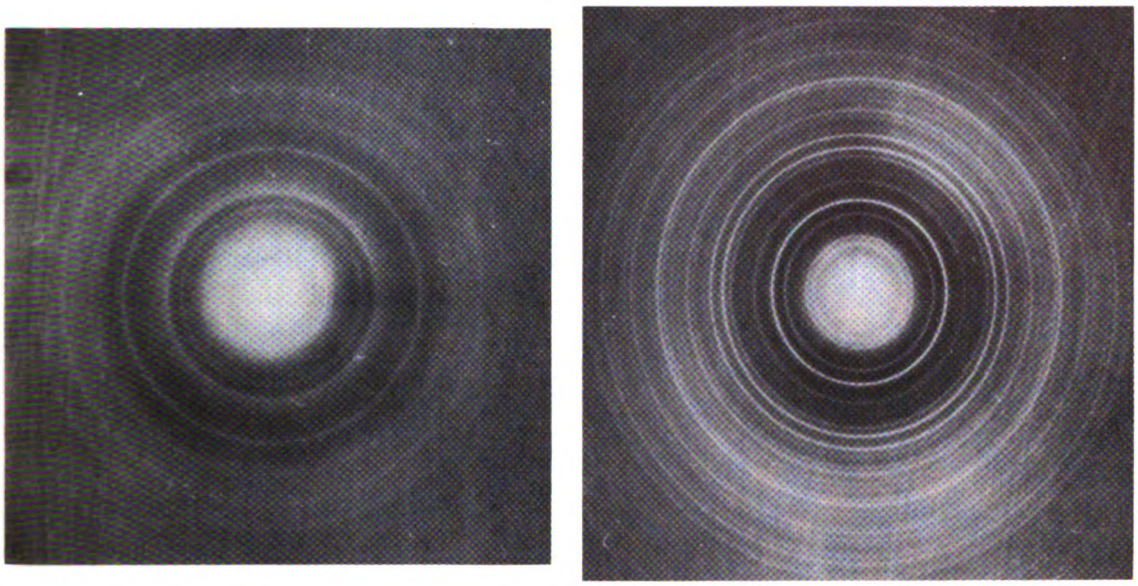

A B

Figure 3. - Electron diffraction patterns of cobalt (A) and iron (B) catalysts that have been used in the Fischer-Tropsch synthesis.

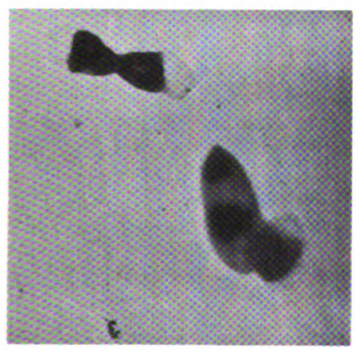

Figure 4. - Electron micrograph of a pure culture of a micro-organism found in acid mine water. 10,300X.

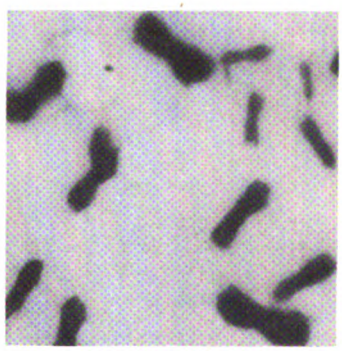

Figure 5. - Electron micrograph of micro-organisms in synthetic acid mine water. 10,300X.

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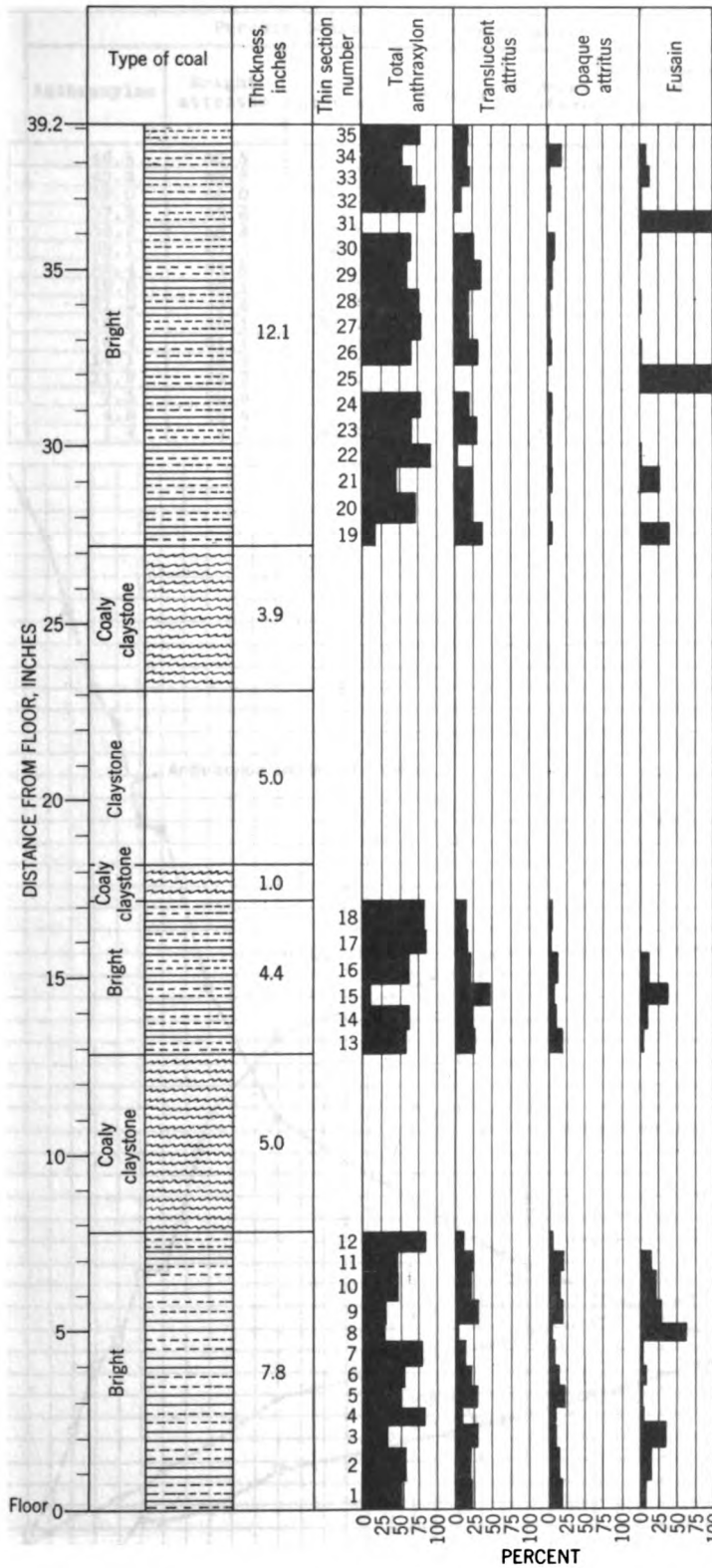

Figure 6. - Types of coal and percentage of components in Fairview Bed, Soot Creek mine, St. Clair County, Ala.

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Specific-gravity fractions	Percent petrographic components						Ash of coal moisture-free basis, percent
	Anthraxylon	Bright attritus	Dull attritus	Fusain	Mineral matter	Anthraxylon and bright attritus	
Float - 1.25	46.5	53.5	-	-	-	100	0.95
1.25 - 1.26	40.2	59.8	-	-	-	100	.90
1.26 - 1.27	32.0	68.0	-	-	-	100	1.15
1.27 - 1.28	37.2	62.8	-	-	-	100	1.53
1.28 - 1.29	36.6	59.8	3.2	0.4	-	96.4	2.31
1.29 - 1.30	25.1	67.6	6.5	.8	-	92.7	3.75
1.30 - 1.31	22.4	63.8	12.9	.9	-	86.2	5.00
1.31 - 1.32	19.8	60.1	18.7	1.4	-	79.9	5.69
1.32 - 1.33	21.2	53.4	20.9	2.2	0.3	76.6	6.74
1.33 - 1.34	18.8	49.1	27.0	4.9	.2	67.9	7.60
1.34 - 1.35	16.4	51.1	27.3	4.9	.3	67.5	9.18
1.35 - 1.37	14.1	38.8	41.1	5.5	.5	52.9	11.65
1.37 - 1.40	11.9	29.2	48.6	9.2	1.1	41.1	15.79
1.40 - 1.50	7.5	20.8	56.0	13.8	1.9	23.3	20.61
1.50 - 1.60	4.8	15.6	56.2	19.6	3.8	20.4	25.76
Sink - 1.60	1.4	4.0	44.8	13.6	36.2	5.4	64.49

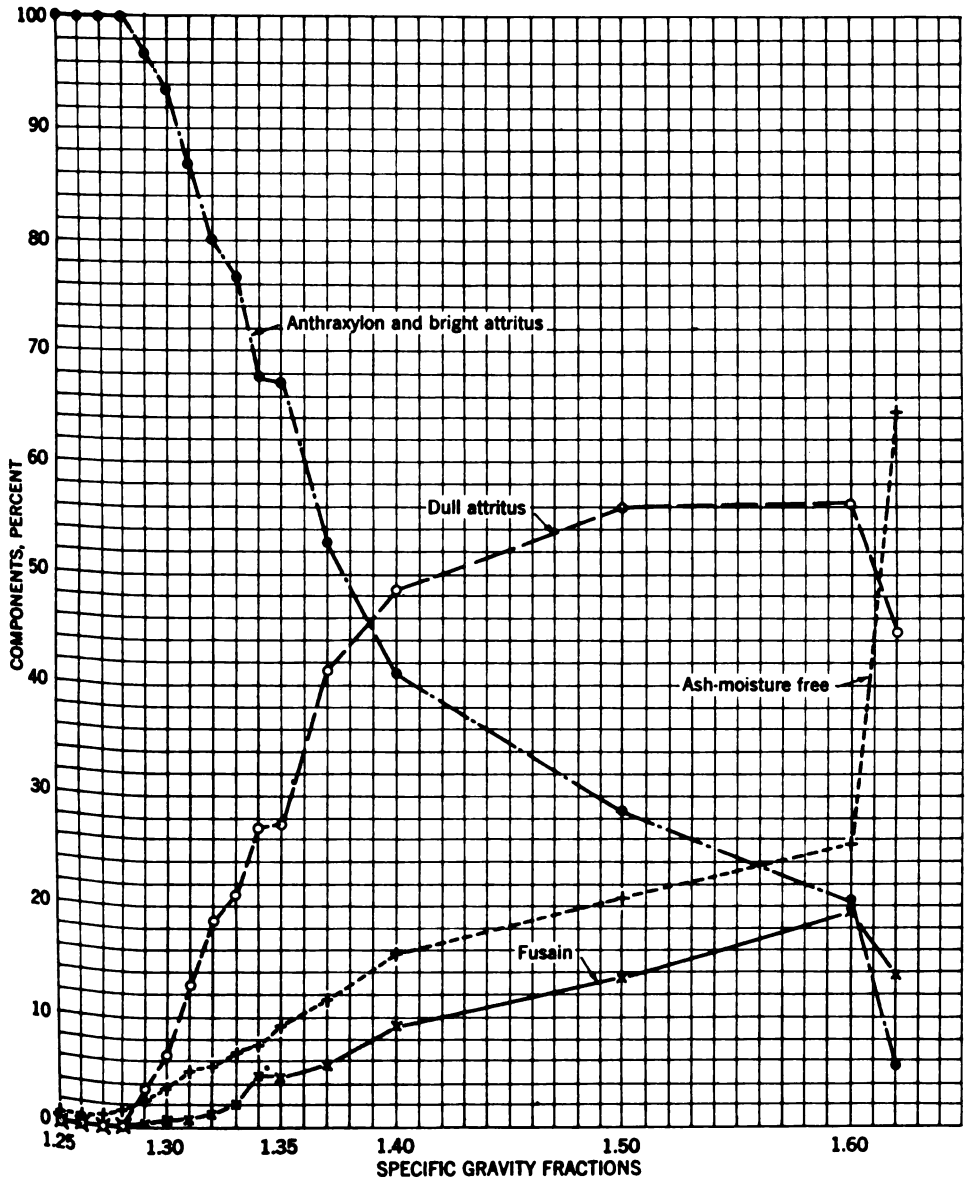

Figure 7. - Percentage of petrographic components of float-and-sink fractions. Rock Springs No. 3 bed coal, Sweetwater No. 2 mine, Sweetwater County, Wyo.

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TABLE 1. - Comparison of petrographic composition of column sample and coal core from the Fairview bed, St. Clair County, Ala.

Coal	Sample	Percent of coal components			
		Anthraxylon	Translucent attritus	Opaque attritus	Fusain
Fairview	Column sample from mine	57.2	20.0	8.3	14.5
Do.	Coal core from drill hole	63.0	20.1	9.1	7.8
Do.	Column sample, fusain-free basis.	67	23	10	
Do.	Coal core, fusain-free basis	68	22	10	

Studies were made of the petrographic composition of 40 coal samples from coal-preparation investigations for synthetic liquid fuels research. The samples consisted of crushed coal of size range 14- by 100-mesh. These samples represented various specific gravity fractions from float at 1.25 sp. gr. to sink at 1.60 sp. gr. Quantitative petrographic analyses of the various gravity fractions were made by particle identification and count using a low-power stereoscopic microscope and accessories. Table 2 shows the source of the coals and petrographic analysis of the specific gravity fractions. Figure 7 shows by graph and table the petrographic composition of 16 specific-gravity fractions of Rock Springs No. 3-bed coal from the Sweetwater No. 2 mine, Sweetwater County, Wyo. All these analyses showed a common characteristic in concentration of anthraxylon and bright attritus in the light-gravity fractions and concentration of dull attritus and fusain in the heavy-gravity fractions. This suggests that gravity separation methods may be useful for obtaining a coal product high in anthraxylon and translucent attritus. These components of coal are hydrogenated more easily to liquid fuels than are the opaque attritus and fusain.

A petrographic study of meta-anthracite occurring in Newport and Providence Counties, R. I.,[15] revealed a preponderance of extremely fine grained minerals identified by X-ray analysis as consisting of large parts of quartz, mica, and chlorite. Mineral graphite, kaolinite, and dolomite also were noted. The minerals found in the meta-anthracite are common to highly metamorphosed rocks and are a secondary indication of the extreme metamorphism which has well-advanced the original coal material toward becoming a true graphitic rock. The high content of dispersed mineral matter strongly suggested that ash reduction by preparation methods would improve the meta-anthracite very little, and it could be considered an extremely low quality fuel at best.

15/ Toenges, Albert L., Turnbull, Louis A., Neale, Arthur, Schopf, J. M., Abernethy, R. F., and Quinn, Alonzo, Investigation of Meta-Anthracite in Newport and Providence Counties, R. I.; Petrography, Chemical Characteristics, and Geology of Deposits: Bureau of Mines Rept. of Investigations 4276, 1948, 37 pp.

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TABLE 2. - Analytic summary of petrographic components of coal samples prepared in connection with coal-preparation studies for synthetic liquid fuels

Sample No.	Specific-gravity fraction	Anthraxylon	Bright attritus	Dull attritus	Fusain	Mineral matter	Source of coal
1	F. 1.25, S. 1.25, F. 1.31	36.2	45.5	9.2	9.1	-	Indiana No. 4 coal, Saxton
2	S. 1.31, F. 1.50	14.6	29.6	31.8	24.0	-	mine, Vigo
3	S. 1.50	3.2	5.7	32.0	41.8	17.3	County, Ind.
4	F. 1.25, S. 1.25, F. 1.33	18.2	58.9	12.8	10.1	-	Mannington coal, Williams mine,
5	S. 1.33, F. 1.50	2.6	13.2	23.7	60.5	-	Hopkins County,
6	S. 1.50	1.3	6.7	16.5	67.7	7.8	Ky.
7	F. 1.27, S. 1.27, F. 1.35	26.9	54.9	16.0	2.2	-	Rosebud coal, Rosebud mine,
8	S. 1.35, F. 1.50	3.3	21.2	50.9	24.6	-	Rosebud County,
9	S. 1.50	1.0	4.2	61.8	18.5	14.5	Mont.
10	F. 1.25, S. 1.25, F. 1.34	33.2	59.0	6.4	1.4	-	Middle Kittanning coal,
11	S. 1.34, F. 1.50	15.9	52.8	11.2	20.1	-	Castner mine,
12	S. 1.50	10.3	24.1	21.3	38.6	5.7	Jefferson County, Ohio
13	F. 1.25, S. 1.25, F. 1.29	31.6	66.0	2.4	-	-	Sunnyside coal, Sunnyside No.
14	S. 1.29, F. 1.50	7.3	51.1	39.7	1.9	-	1 mine, Carbon
15	S. 1.50	.6	8.4	57.5	16.9	16.6	County, Utah
16	F. 1.25, S. 1.25, F. 1.31	25.0	53.5	18.5	3.0	-	No. 5 Block coal, Colcord No. 5
17	S. 1.31, F. 1.50	5.5	28.9	42.2	23.4	-	mine, Raleigh
18	S. 1.50	.8	5.3	75.3	17.1	1.5	County, W. Va.
19	F. 1.29, S. 1.29, F. 1.31	31.5	57.7	6.5	4.3	-	Monarch coal, Sheridan mine,
20	S. 1.31, F. 1.50	19.3	32.6	17.5	30.6	-	Sheridan
21	S. 1.50	3.7	6.7	18.4	64.5	6.7	County, Wyo.
22	F. 1.29, S. 1.29, F. 1.31	32.8	64.5	2.5	.2	-	Mammoth coal, Elkol mine,
23	S. 1.31, F. 1.37	24.7	63.9	9.3	2.1	-	Lincoln County,
24	S. 1.37		4.5	10.4	3.4	81.7	Wyo.

Thin sections of the Beaver Hill coal bed in the Coos Bay coal field were examined microscopically and some significant petrographic characteristics were found.16/ About 30 percent of the coal consisted of anthraxylon bands wide enough to be distinguished with the unaided eye. Fusain was not present, and total opaque matter in no instance exceeded 1 percent of the coal. Clay minerals and pyrite, finely dispersed in the coal, were the principal ash-forming ingredients recognized with the microscope.

16/ Toenges, Albert L., Dowd, James J., Turnbull, Louis A., Schopf, J. M., Cooper, H. M., Abernethy, R. F., Yancey, H. F., and Geer, M. R., Minable Reserves, Petrography, Chemical Characteristics, and Washability Tests of Coal Occurring in the Coos Bay Coal Field, Coos County, Oreg.: Bureau of Mines Tech. Paper 707, 1948, 56 pp.

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Heating-Value Loss During Air Drying of Coal

The standard method for analyzing coal specifies that all wet coal be air-dried before final preparation of the laboratory sample. As there has been some criticism of the possible loss of heating value from excessive air drying, a series of tests was made of coals of several ranks to evaluate the degree of oxidation, or loss of heating value, caused by air-drying according to standard practice. The results of the investigation[17] showed that:

The percentage of heating-value loss depends on the rank of coal, since changes in low-volatile bituminous coals were not detected, and high-volatile C bituminous and subbituminous B coals were oxidized slightly, with resulting slight loss in heating value;

The heating-value loss due to 1 or 2 days' drying beyond the time when the air-dry loss is less than 0.1 percent per hour, is negligible;

The heating-value determination of low-rank coals should be made as quickly as possible after collection of samples.

Determination of Moisture in Coal

A series of tests was made to compare the percentages of moisture in coal obtained by the A. S. T. M. standard procedure with those using the Brabender Semi-automatic Moisture Tester, an instrument that has been used to determine rapidly the moisture content of textiles, cellulose, feeds, foodstuffs, etc. The results[18] showed that the moisture values for coal obtained with the Brabender apparatus are within the permissible tolerances of those obtained by the A. S. T. M. procedure, except for anthracite. The drying rates by the A. S. T. M. and Brabender procedures were similar, and it was found that the drying time for high-rank coals could be reduced for both procedures.

Float-and-Sink Testing of Lignite

Since float-and-sink tests applied to bituminous coals give erratic results on air-dried lignite, an investigation was made of the effect of moisture in the float-and-sink testing of lignite. Tests[19] made on North Dakota lignite showed that (1) the yield of float material in a float-and-sink test is greatly influenced by the moisture content as tested; (2) air-dried lignite differs from bituminous coal in that it cannot be restored to its original state by saturating with water; (3) saturating air-dried lignite with a gasoline-carbon tetrachloride mixture has no effect on the results; (4) lignite coarser than 14-mesh can be tested in organic solutions without air-drying; and (5) order in which a sample is tested through a series of solutions is without effect on the results.

17/ Cooper, H. M., Tarpley, E. C., and Abernethy, R. F., Heating-Value Loss of Coal on Air-Drying: Bureau of Mines Rept. of Investigations 4197, 1948, 6 pp.

18/ Cooper, H. M., Tarpley, E. C., and Abernethy, R. F., Determination of Moisture in Coal with the Brabender Semiautomatic Tester: Bureau of Mines Rept. of Investigations 4304, 1948, 15 pp.

19/ Cooper, H. M., Tarpley, E. C., and Abernethy, R. F., Effects of Moisture on the Float-and-Sink Testing of Lignite: Bureau of Mines Rept. of Investigations 4184, 1947, 8 pp.

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Free-Swelling Index of Coal

Bureau of Mines Report of Investigations 3989 was revised.[20] This gives the results of a study of the American Society for Testing Materials Standard Method of Test for Free-Swelling Index of Coal, A. S. T. M. Designation: D 720 - 46. The report discusses some of the results obtained by the Bureau of Mines after the test was begun in 1938 and procedures to overcome difficulties with coals giving carbonized buttons whose shapes do not correspond with the standard profiles. It was concluded from the study that the test is valuable for obtaining information regarding the coking and caking properties of coal on fuel beds, but it should not be used as a measure of the amount of expansion or contraction that takes place during carbonization of coal in coke ovens and is not recommended for this purpose. A simple method for obtaining free-swelling indexes of coals whose shapes do not conform to any of the standard profiles is described, whereby the index can be obtained from a curve relating the cross-sectional areas of the buttons to the swelling-index numbers.

COAL MINING

Experimental Mine and Dust Explosions

Demonstrations

Educational demonstrations of the hazards of mine explosions and of means for preventing them were continued for the benefit of workers and officials of the coal-mining industry, for mining students, and for others. Of five public demonstrations at the Experimental coal mine, attended by more than 600 people, one was held for the benefit of the Technical Committee of the National Fire Protection Association and another for the American Institute of Electrical Engineers.

A routine demonstration of methods of extinguishing mine fires was given at the Experimental coal mine for the benefit of coal-mine officials, fire bosses, and foremen to show the efficacy of water containing a wetting agent on a standard floor, rib, roof fire developed by the Bureau. It was attended by about 250 people.

Technical Assistance and Services to Others

Based on experiments in the laboratory, data were furnished the National Fire Protection Association on the limiting percentage of oxygen in the atmosphere to prevent explosion of carbonaceous dusts. The National Fire Protection Association also was assisted in revising the tentative code for explosion pressure release.

Preventing Propagation of Coal-Dust Explosions in Mine Rooms

As a result of certain requirements for rock-dusting coal mines promulgated in the Federal Mine Safety Code for Bituminous-Coal and Lignite Mines of the United States, July 24, 1946, an investigation was conducted in the Experimental coal mine, at the request of the Coal Mines Administration.[21] The objectives were to determine

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20/ Selvig, W. A., and Ode, W. H., An Investigation of a Laboratory Test for Determination of the Free-Swelling Index of Coal: Bureau of Mines Rept. of Investigations 4238, 1948, 11 pp.

21/ Howarth, H. C., Nagy, John, Hartmann, Irving, Greenwald, H. P., and Lewis, Bernard, Tests in the Experimental Coal Mine to Determine Requirements for Preventing Propagation of Coal Dust Explosions in Rooms: Bureau of Mines Rept. of Investigations 4195, 1948, 12 pp.

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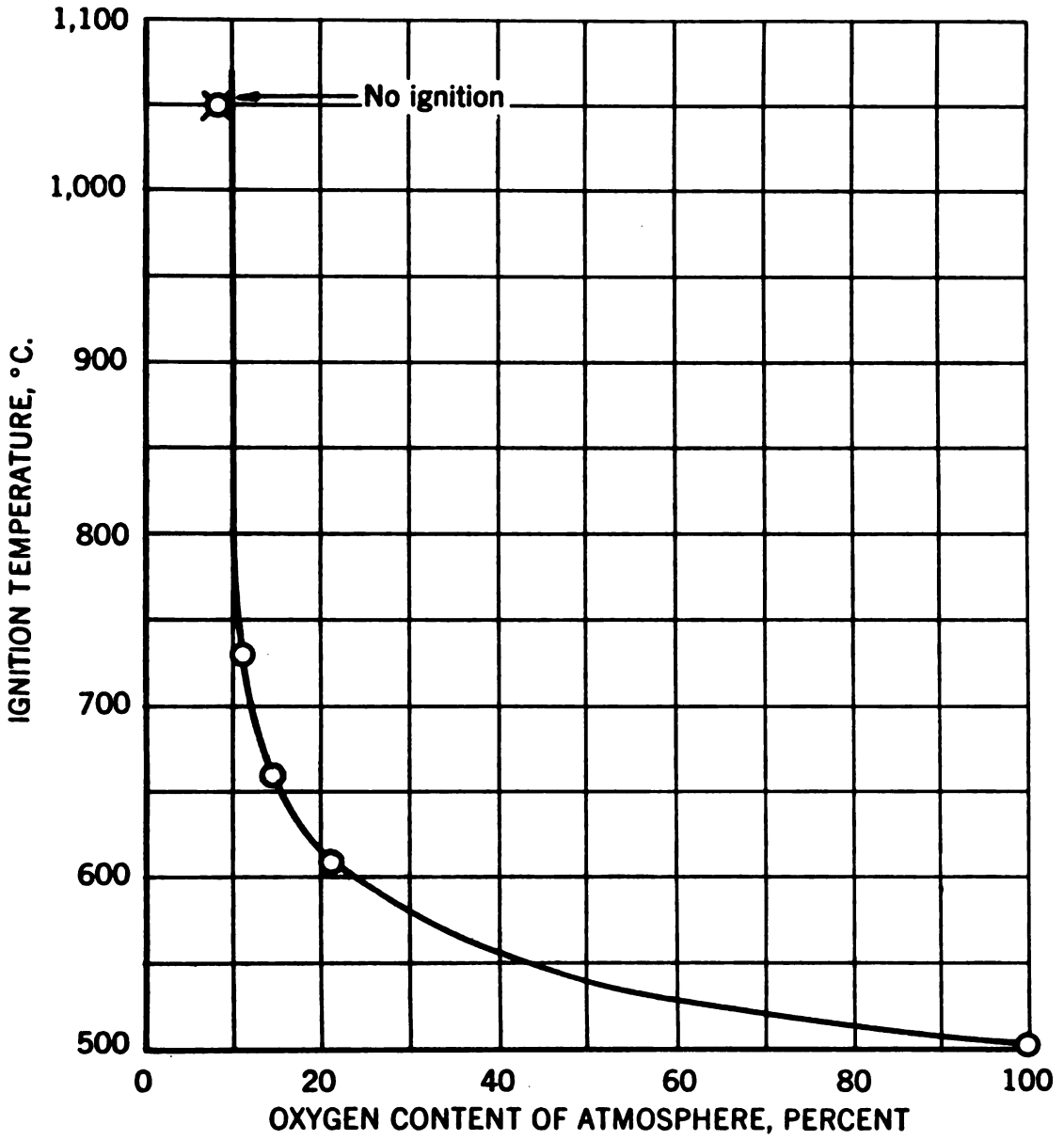

Figure 8. - Effect of oxygen content of atmosphere on the ignition temperature of dust clouds of minus 200-mesh Pittsburgh coal.

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how rock-dusting requirements in short, wide rooms compare with those in long, narrow entries; the effect of crosscuts between rooms; and whether bag-type devices,[22] or modifications thereof now in use, are effective in preventing propagation of an explosion from a room into adjacent rooms and into the entry from which the room is turned.

The investigation led to the following conclusions:

1. Propagation of coal-dust explosions originating in single, narrow or wide, coal-mine rooms or workings of relatively short length can be prevented by generalized rock dusting carried up to within 40 feet of the working face if the incombustible content of the dust is maintained above 65 percent. Rock dust carried up to within only 80 feet of the working face will not prevent propagation of coal-dust explosions in such workings.

2. To prevent the propagation of coal-dust explosions in wide, connecting workings or rooms, a minimum of 65 percent incombustible material in the dust must be maintained up to within 40 feet or less of the working face.

3. Bag-type rock-dust protective devices tested thus far are ineffective in preventing the propagation of explosions either between connected rooms or from rooms into entries. The chief cause of failure of these devices is that the rock dust is not adequately dispersed into the air stream at the proper moment. The arrangements that were tested were those that could be installed readily in commercial mines. They leave the trackway in rooms unprotected. To be effective, any improved form of these devices must have more positive means of operation, so as to disperse efficiently at least 70 percent of the rock dust at the proper moment, and be capable of installation over track or other haulageways so that the entire width of the room is protected.

Effect of Oxygen Content of the Atmosphere on Ignition Temperature of Coal Dust

The composition of the atmosphere, particularly its oxygen content, has profound effects on the initiation and development of dust explosions. Experiments have shown[23] that, as the oxygen content of the atmosphere is reduced, the ignition temperature of dust clouds is increased. This is illustrated for fine Pittsburgh coal dust in oxygen, in air, and in mixtures of air and carbon dioxide (fig. 8). Other experiments have shown that reduction of the oxygen content by dilution of air with carbon dioxide or nitrogen reduces the relative inflammability of dust clouds.

Coal Investigations

Toledo, Lewis County, Wash.

The results of an investigation of a lignite deposit near Toledo, Lewis County, Wash., were published.[24] The center of the area is approximately 9 miles west of

[22] Greenwald, H. P., and Howarth, H. C., Tests of a Barrier Using Rock Dust in Paper Bags: Bureau of Mines Rept. of Investigations 3411, 1948, 16 pp.

[23] Hartmann, Irving, Recent Researches on the Explosibility of Dust Dispersions: Ind. Eng. Chem., vol. 40, No. 4, April 1948, pp. 752-758.

[24] Toenges, Albert L., Turnbull, Louis A., and Cole, Willard A., Exploration, Reserves, Bed Characteristics and Strip Mining Possibilities of a Lignite Deposit near Toledo, Lewis County, Wash.: Bureau of Mines Tech. Paper 699, 1947, 55 pp.

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Toledo, Wash. (see fig. 9) and approximately midway between Tacoma, Wash., and Portland, Oreg. Thirty-five diamond-drill holes were put down, and these determined the extent of the deposit and the limit of the area favorable for strip mining (see fig. 10).

An area of lignite approximately 4,750 feet long, northwest-southeast, and a maximum of 1,700 feet wide, northeast-southwest, which can be mined by stripping methods, was delineated by the investigation. The estimated proved reserve of lignite in the lens is 8,031,000 tons, assuming that both the upper and lower benches of the lignite lens will be mined. Of this, 5,317,000 tons, under a maximum overburden of 65 feet, are considered minable by stripping methods. The area of the strippable tonnage is estimated at 142.5 acres. The average thickness of overburden in this area is 42 feet, and the stripping ratio is 1.7 cubic yards of overburden plus first main parting per ton of recoverable lignite.

A method of operation considered adaptable to this deposit would be to strip off the overburden with a medium-size power shovel and transport the spoil in trucks for disposal beyond the limits of the lignite lens, or by using tractor-scraper units to both excavate and transport the overburden. This method has advantages over the use of large power shovels or draglines and overcasting, because of the topography, the characteristics of the overburden, the wet winter months, and the occurrence of the lignite in two minable benches separated by a thick parting. The mining of the upper bench of lignite, the removal of the first main parting, and the mining of the lower bench of the lens should be so planned that production of lignite from the two benches is balanced.

Coos Bay, Oreg.

Some of the fuel requirements of the Pacific Northwest are met from the Coos Bay coal field. The results of an investigation to determine the minable reserves in a portion of the coal field were published.25/ The area investigated was approximately 6 miles long, north and south, and extended from 4 miles south of Coos Bay, formerly Marshfield, Oreg., to the Old Beaver Hill mine (see fig. 11).

The drilling and surface excavations (see fig. 12) show that the Beaver Hill bed is the most important coal bed in the area. The bed comprises 3 benches of subbituminous B coal separated by partings. The upper bench is the thinnest and is usually left for mine roof. The middle and lower benches usually are recovered in mining.

Diamond drilling proved 1,020 acres of land in the area to be underlain by Beaver Hill coal. In addition to this proved area, there are 142 acres of indicated and 435 acres of inferred reserves of Beaver Hill coal.

25/ Toenges, Albert L., Dowd, James J., Turnbull, Louis A., Schopf, J. M., Cooper, H. M., Abernethy, R. F., Yancey, H. F., and Geer, M. R., Minable Reserves, Petrography, Chemical Characteristics and Washability Tests of Coal Occurring in the Coos Bay Coal Field, Coos County, Oreg.: Bureau of Mines Tech. Paper 707, 1948, 56 pp.

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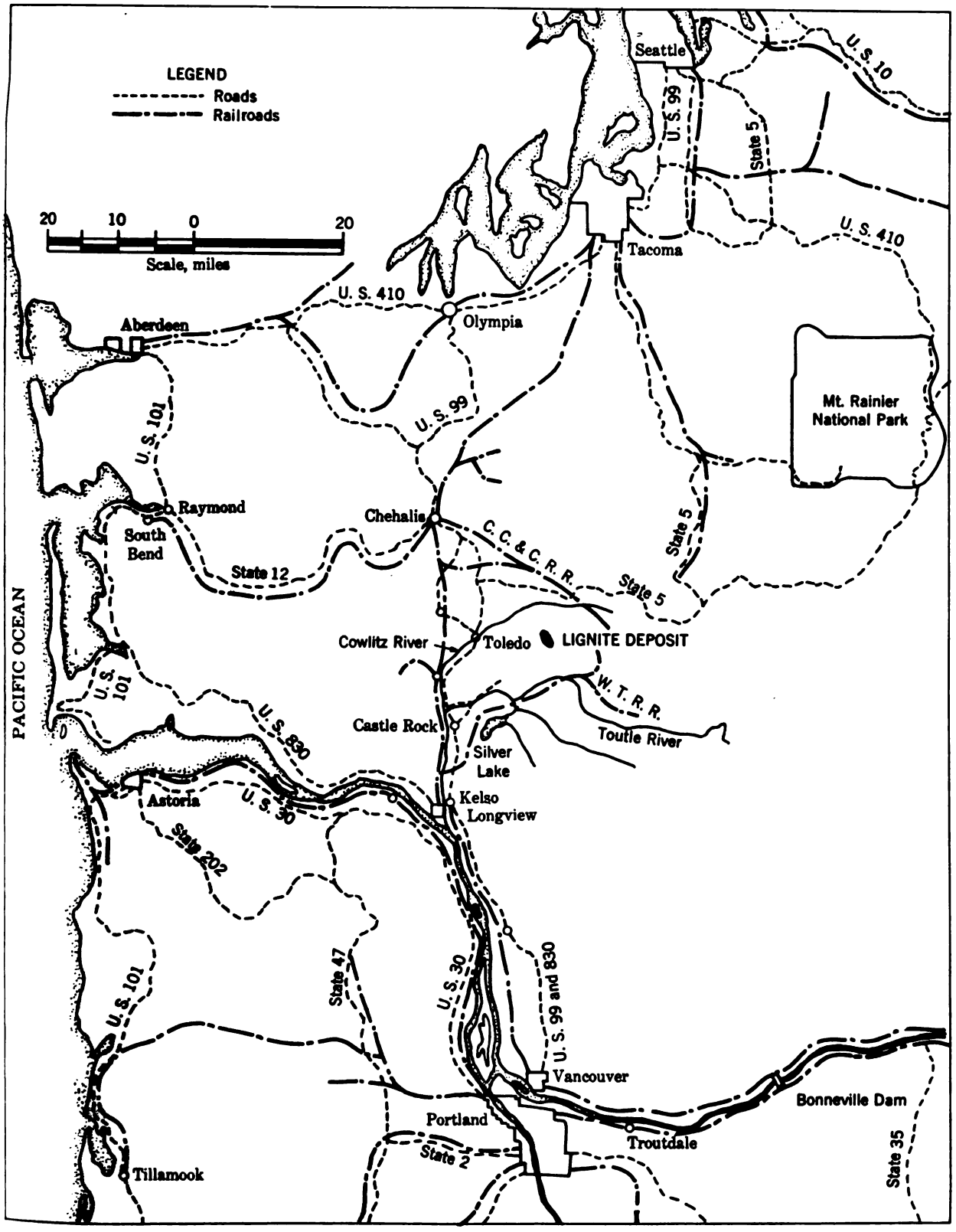

Figure 9. - Location of Toledo, Wash., lignite deposit.

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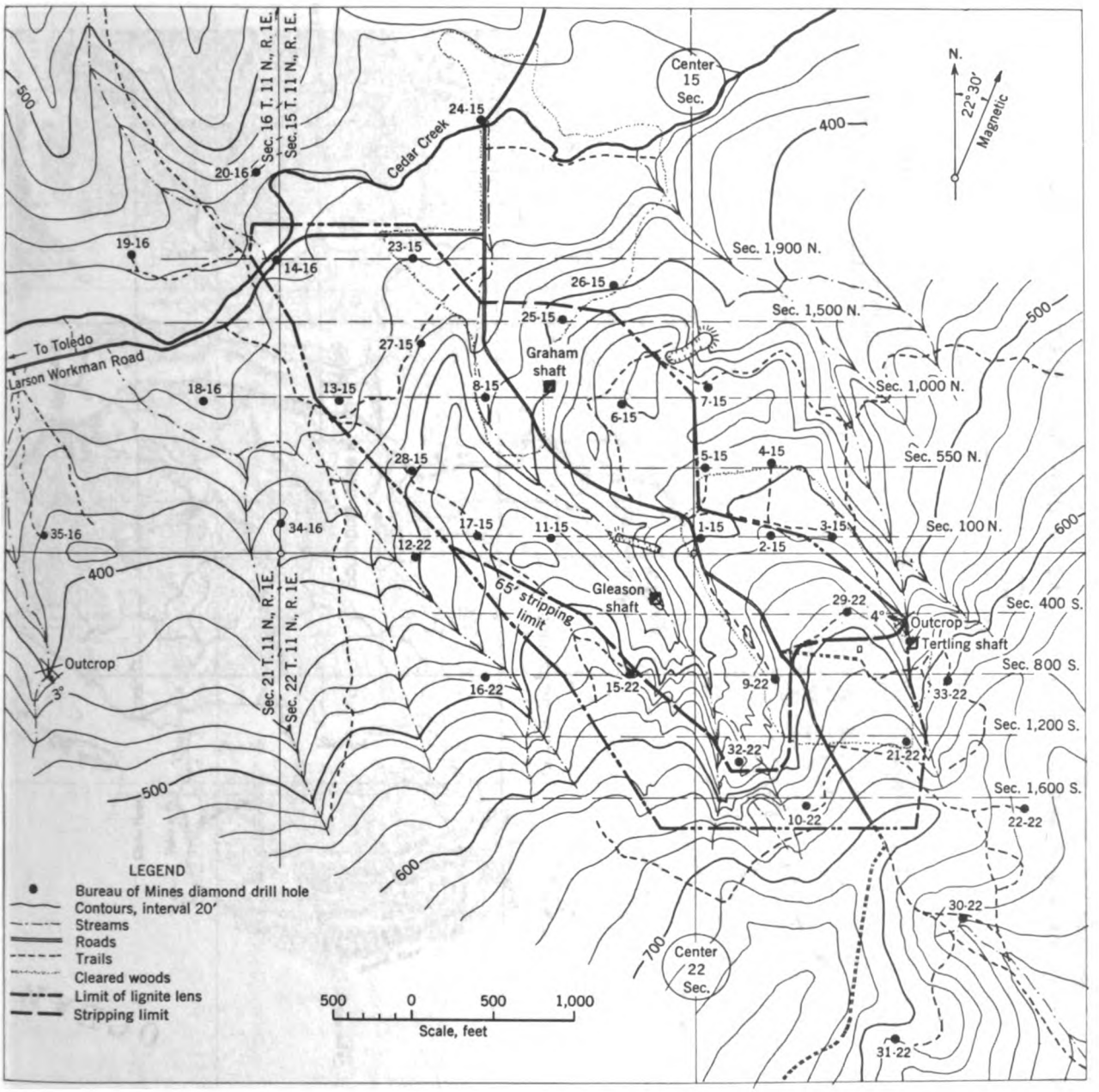

Figure 10. - Exploration secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., near Toledo, Lewis County, Wash. (Prepared from map compiled by Geology of Fuels Section, U. S. Geological Survey.)

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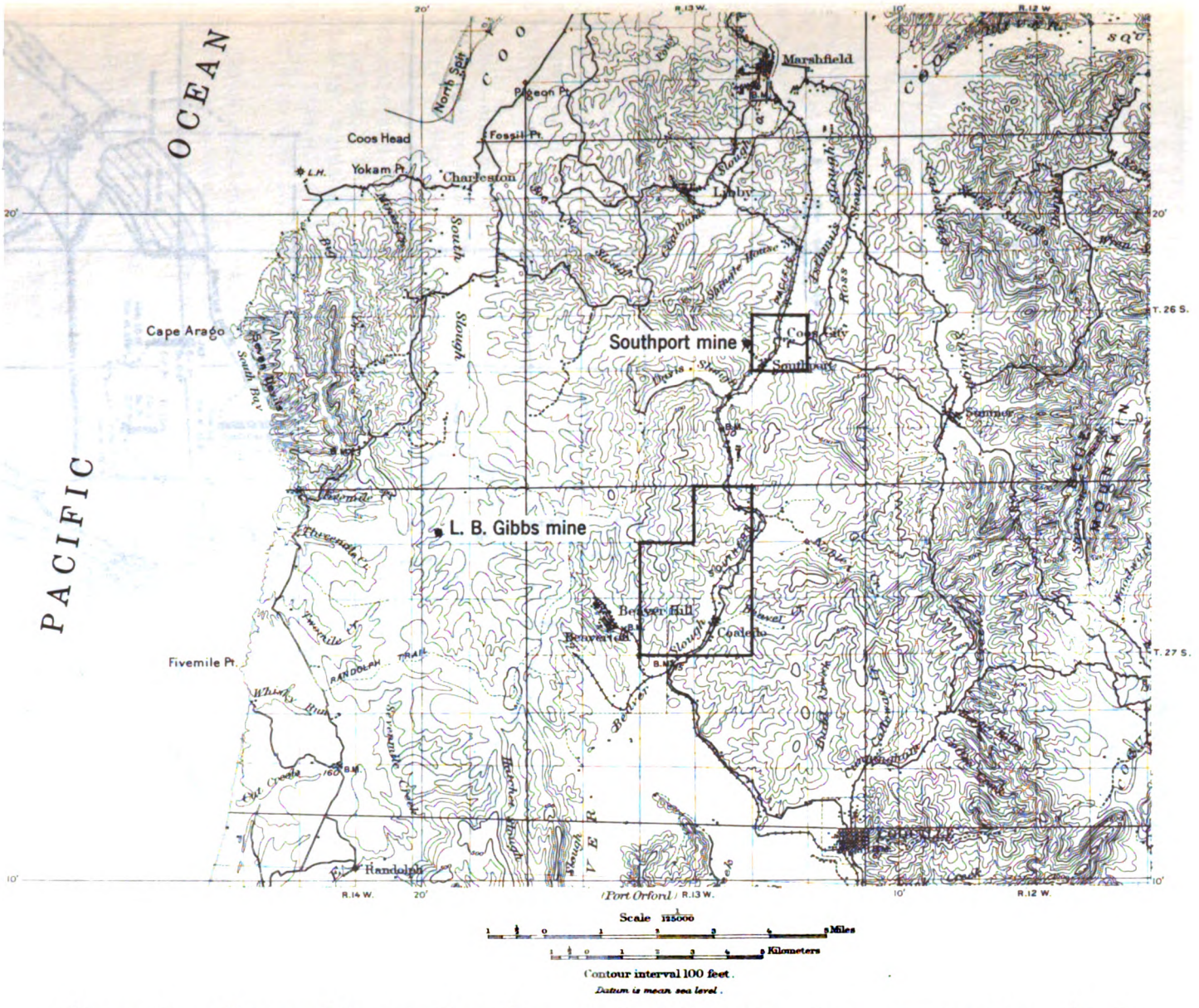

Figure 11. - Topographic map of region. Part of Coos Bay, Oreg., quadrangle. (U. S. Geological Survey.)

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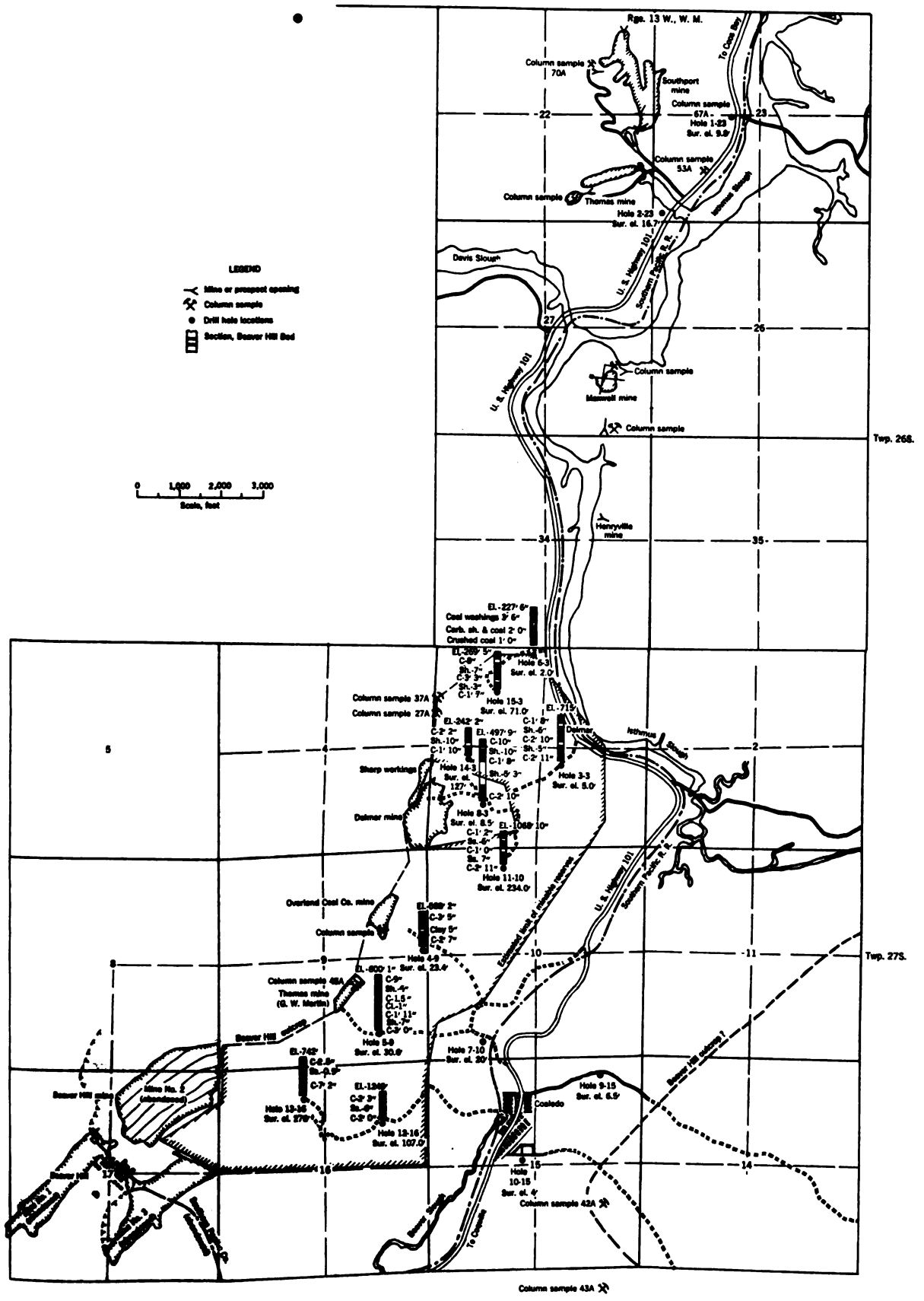

Figure 12. - Diamond drilling in Beaver Hill coal bed, Tps. 26 and 27, R. 13 W., Coos County, Oreg.

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Proved, indicated, and inferred reserves were summarized as follows:

TABLE 3. - Summary of proved, indicated, and inferred reserves

	Average thickness of bed		Acres	Total reserves, tons
	Ft.	In.		
Proven	6	5	1,020	10,809,900
Indicated	6	8	142	1,646,600
Inferred	6	0	435	4,546,600
			1,597	17,003,100

The minable reserves are estimated at 13,602,000 tons, based on 80 percent recovery of the coal in the area.

Washability tests, made on coal from two mines near the area investigated, indicate that the coal can be washed successfully. Samples of the Beaver Hill coal used in the washability tests included all of the partings in the bed. Results of these tests show that about 80 percent of the raw coal can be recovered in washing, reasonable recovery and that the ash content of this washed coal will be about 10 or 11 percent, eliminating practically all of the parting material. The coal can be mined mechanically.

Meta-Anthracite in Newport and Providence Counties, R. I.

The fuel requirements for industrial and domestic consumers in New England are supplied almost entirely by fuel oil, anthracite, and bituminous coal. Shortages of these fuels led to an investigation of possible sources of fuel nearer to points of consumption in New England.

Meta-anthracite, which is a satisfactory fuel for some purposes, had been mined in Massachusetts and Rhode Island many years ago. The coal from mines in the vicinity of Portsmouth on Aquidneck Island, Newport County, R. I., had been used successfully for smelting copper ore and for fuel. The introduction of freer-burning anthracite and bituminous coal into New England markets resulted in abandonment of these mines. With the present-day development of improved equipment for burning coal, methods of burning it probably could be devised, should minable reserves of coal be found. Diamond drilling was undertaken to determine the characteristics and continuity of the beds in the Portsmouth area.26/

Three vertical diamond-drill holes to recover 2-1/8-inch cores were drilled from surface locations on the north end of Aquidneck Island in the town of Portsmouth. The Cranston mine, of Graphite Mines, Inc., also was examined.

The results of the investigation of the Portsmouth and Cranston areas are summarized as follows:

1. Investigation by diamond drilling and geological examination in the Portsmouth area on Aquidneck Island indicates that minable beds of meta-anthracite

26/ Toenges, Albert L., Turnbull, Louis A., Neale, Arthur, Schopf, J. M., Abernethy, R. F., and Quinn, Alonzo W., Investigation of Meta-Anthracite in Newport and Providence Counties, R. I., Petrography, Chemical Characteristics, and Geology of Deposits: Bureau of Mines Rept. of Investigations 4276, 1948, 37 pp.

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are not continuous over appreciable areas, and no estimate can be made of possible reserves in this vicinity.

2. The exposed faces in the workings of the Cranston mine of Graphite Mines, Inc., indicate that there is a recoverable reserve of meta-anthracite adjacent to the workings of this mine. The recoverable reserves cannot be estimated, because the structure and thickness of the bed may change sharply in any direction. The bed may "pinch" out or may be dislocated by faulting.

3. Petrographic examination of cores and mine samples shows that most of the coal of the Narragansett Basin has been subjected to intensive minor faulting and brecciation.

4. The dry ash ranges from 76.1 to 93.7 percent and total carbon from 1.8 to 19.5 percent. With a single exception, the analyses of the cores compared with analyses of meta-anthracite from Cranston and Portsmouth mines showed that the other cores cannot be classified as coal.

Coal Creek, Gunnison County, Colo.

The investigation of coking-coal reserves in this area by diamond drilling was continued and will be completed early in the fiscal year 1949. A diamond-drill hole to secure minimum 8-inch coal cores for carbonization tests is being drilled.

Castleman Basin, Md.

Diamond drilling at this project was in progress at the end of the fiscal year. To date, 21 holes (15,000 feet) have been drilled. Eleven coal beds are present in the area. However, the Lower Bakerstown, Upper Freeport, and Upper Kittanning beds appear, from the investigation thus far, to offer the best conditions for future development. The work will be completed in the fiscal year 1949.

Deep River, N. C.

Drilling difficulties, occasioned by caving ground at depth, has retarded the progress of the work on this project. It has been necessary to redrill three times. The third hole reached a depth of 2,167 feet at the end of the fiscal year. The Cumnock coal bed is anticipated at a depth of 2,300 feet. The investigation of this part of the coal field will be completed early in the fiscal year 1949.

Eska Creek, Matanuska Valley, Alaska

Work on this project was begun at the beginning of the fiscal year and recessed in October 1947 because of extreme weather conditions. Drilling was begun again in May 1948. Seven diamond-drill holes (4,000 feet) completed to date show that the coal beds mined at the Eska mine are not continuous at minable thickness in this area. Work at this project will be completed early in the fiscal year 1949.

Mining Methods and Practices

At the request of the Division of Geology, Arkansas Resources and Development Commission and the Arkansas-Oklahoma Coal Operators Association, a preliminary study of mining methods and practices in western Arkansas was made, with the objective of suggesting ways of reducing cost of mining.

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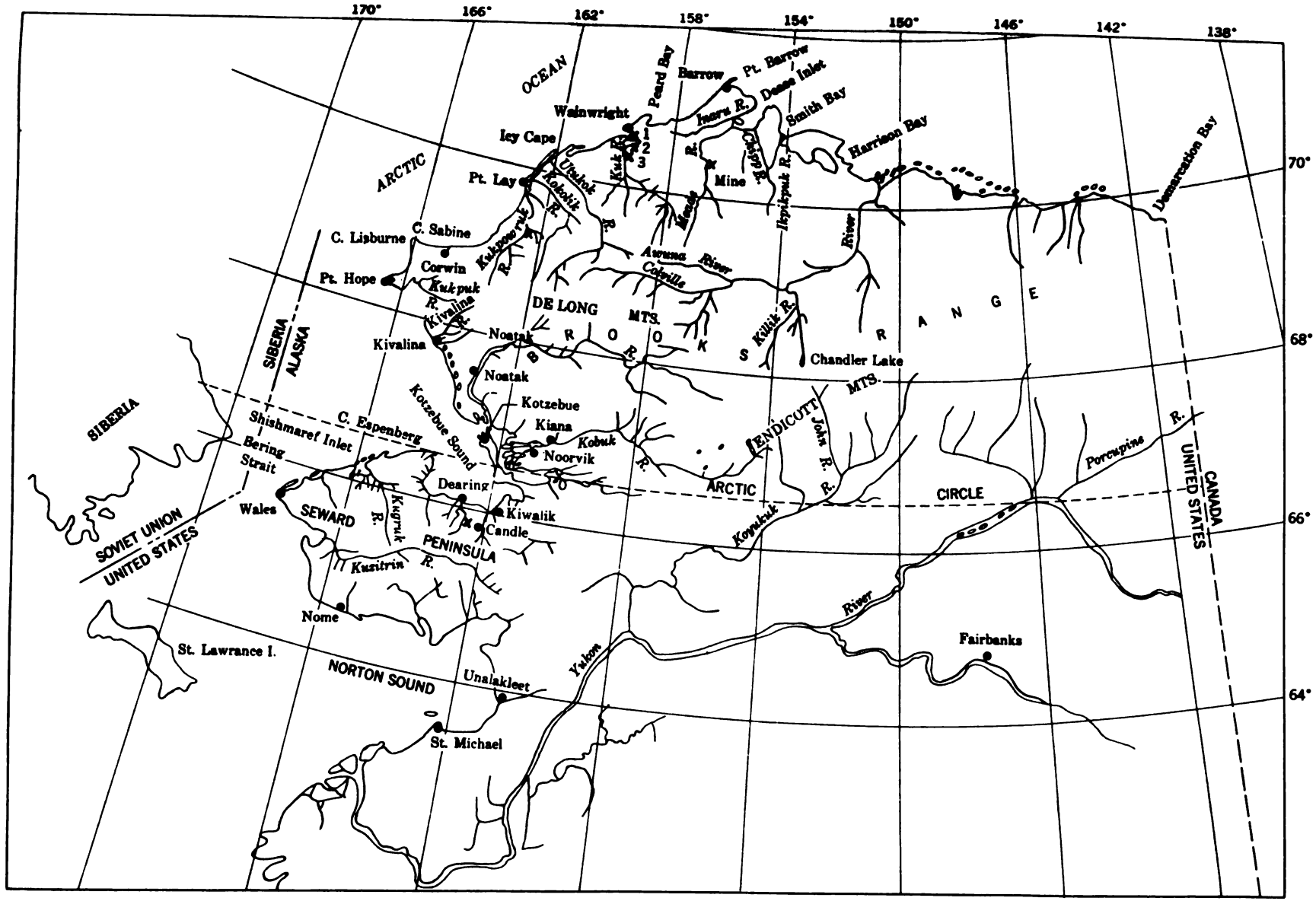

Figure 13. - Location map showing areas investigated (marked by x) in the Arctic regions of Alaska.

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Studies of mechanical mining in bituminous-coal mines were continued, with particular emphasis on the extraction of pillars with mechanical equipment and the effect of the introduction of this equipment on percentage of recovery of coal. Data on mechanized mining and actual percentage of recovery at a number of mines are being correlated for publication.

A study of coal-mining methods and practices and electrical power demands in the Missouri River Basin was begun this year, and an investigation of coal mining in the Bull Mountain field, south central Montana, was completed.

Coal Mining in Europe

The conditions and methods used in mining coal in several European countries were studied by a representative of the Bureau to obtain accurate ideas of methods to be considered in improving those of American mines and to find ways to increase European production. Published reports indicate that Spanish resources are sufficient for that country's requirements; but production is restricted by lack of miners, equipment and power and by Government policy;[27] Italian resources are inadequate, and production has not met requirements;[28] in other countries the situation is changing, but details of production and resources are presented.[29]

Mining of Coal for Local Use in Arctic Regions of Alaska

In connection with development of coal deposits near Government schools, hospitals, and villages in the Arctic regions of Alaska, a reconnaissance was made of a number of deposits.[30]

The construction of frame houses in recent years, instead of the use of the conventional sod hut (igloo), by the Eskimos in the villages along the Arctic Ocean has increased the demand for fuel in these villages. The frame houses, which are not insulated against extreme cold and are difficult to heat, are equipped with coal stoves. The lack of development of coal deposits in the Arctic has made it necessary to import coal from the States by boat at high cost.

It was concluded from investigations of coal deposits in the vicinity of Deering, Point Lay, and Wainwright (fig. 13) that plans for mining coal in the Arctic regions of Alaska for native villages should be based upon natural conditions of the coal beds; climatic conditions, that is, freezing and thawing; short winter hauls by land; summer long hauls by water; reduction of present cost of coal; native ability; native economy; shortage of timber and proper supervision. Two plans can be followed: The first would be the development of local sources of coal at points nearest each village or group of villages; the second is the development of one source of coal, the transportation of coal to a stock pile on the Arctic coast, and transportation of this coal by barge to the various villages when the Arctic Ocean is free of ice along the shore.

27/ East, J. H., Jr., Information on Coal Mining in Spain: Bureau of Mines Inf. Circ. 7396, 1947, 27 pp.

28/ East, J. H., Jr., Italy's Coal Quandary - Dire Need, Diverse Effect: Foreign Commerce Weekly, vol. 26, No. 7, Feb. 15, 1947, pp. 67, 25, 26.

29/ East, J. H., Jr., The European Coal Situation: Mines Mag., vol. 36, No. 4, April 1946.

30/ Toenges, Albert L., and Jolley, Theodore R., Investigation of Coal Deposits for Local Use in the Arctic Regions of Alaska, and Proposed Mine Development: Bureau of Mines Rept. of Investigations 4150, 1947, 19 pp.

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Bituminous coal in a deposit on the Kukpowruk River (fig. 14), approximately 45 miles upstream from Point Lay (about 35 air miles S. 20° E.), does not show degradation after long exposure to the weather. As the coal can be transported long distances with little or no degradation, this area may be considered under the second plan.

Development of Anthracite-Mining Machinery

A loading machine designed and built by the Bureau to solve the problem of transportation delays in mechanizing development work in thin, steeply pitching anthracite beds was modified by redesign and reconstruction of the front and rear drive-trough-support assemblies and replacement of the sleeve-type bearings by roller-type. Other minor changes were made to minimize spillage of fines around the machine, and plans have been carried out to electrify the scraper-end interchangeably with the original air-motor drive. The machine is shown in figure 16.

The principle of planing friable or crushed coal beds was demonstrated by Germany's wartime development of a rigid-blade planer. For planing anthracite or hard bituminous coals, the Bureau has undertaken the design and manufacture of a vibrating-blade type. Design was 70 percent completed in fiscal year 1948.

The 9-hp. Eickhoff (vertical) shearing machine (fig. 15) and the 20-hp. Korfmann universal shearing machine proved so efficient that, after slight changes for better mobility that are under way now, these machines will be used for driving a trackless gangway and companion airway in a 10-foot bed pitching 85°. An engineering study of the mine where these compressed-air-powered machines are to be used showed that with these machines less compressed air is used per yard advance than has been used in hand mining; and that, to drive this development work by hand, will cost 40 percent more than to drive it by machine, equipment and operating costs included.

Mining of Thick-Bed Pillars in Anthracite

The Bureau of Mines is participating in the establishment of a mechanical mining system for removing 50-foot pillars in a relatively flat anthracite bed ranging in thickness from 24 to 28 feet. A working committee, consisting of colliery and central management officials and one Bureau engineer, has investigated top-slicing and back-filling methods in the zinc mines of New Jersey and hydraulic flushing of thick, flat anthracite beds in the Southern anthracite field of Pennsylvania. An engineering-cost study was initiated to determine the practicability of pneumatic back filling by using the Bureau's pneumatic packing machine, which was obtained from Germany a year ago.

In addition, the Bureau has completed contracts for purchasing two lightweight shearing machines from Germany for driving small openings into the pillars. The cooperating company has designed and is building a special remote-control loading machine for loading the coal to be cut by the Bureau's machine.

Anthracite-Flood Prevention

The flooding of active and abandoned anthracite mines in Pennsylvania was investigated by obtaining data on: (1) Anthracite reserves, (2) underground water pools, (3) barrier pillars, (4) the "buried valley" of the Susquehanna River, and

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Figure 14. - Coal deposit on Kukpowruk River, approximately 45 miles upstream from Point Lay, Alaska.

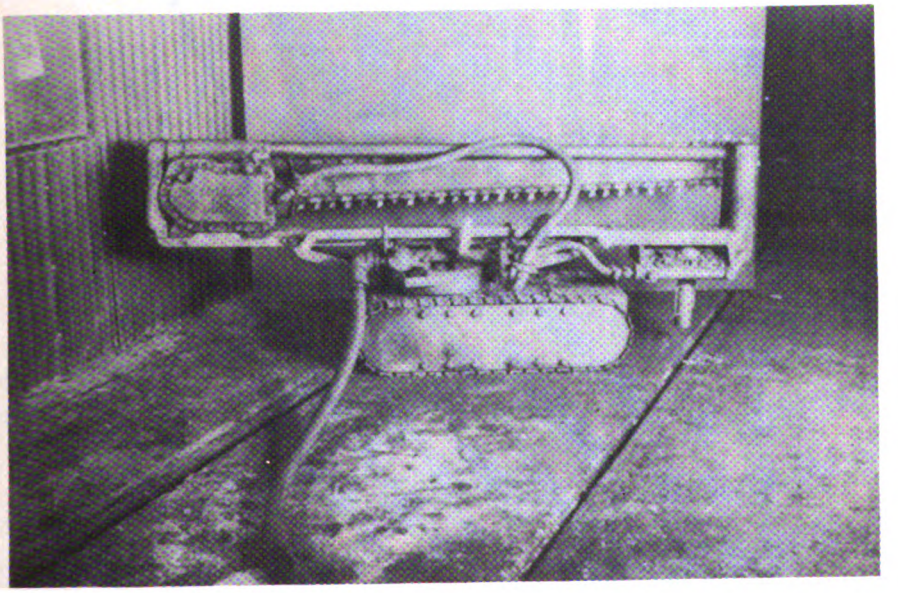

Figure 15. - Eickhoff shearing machine.

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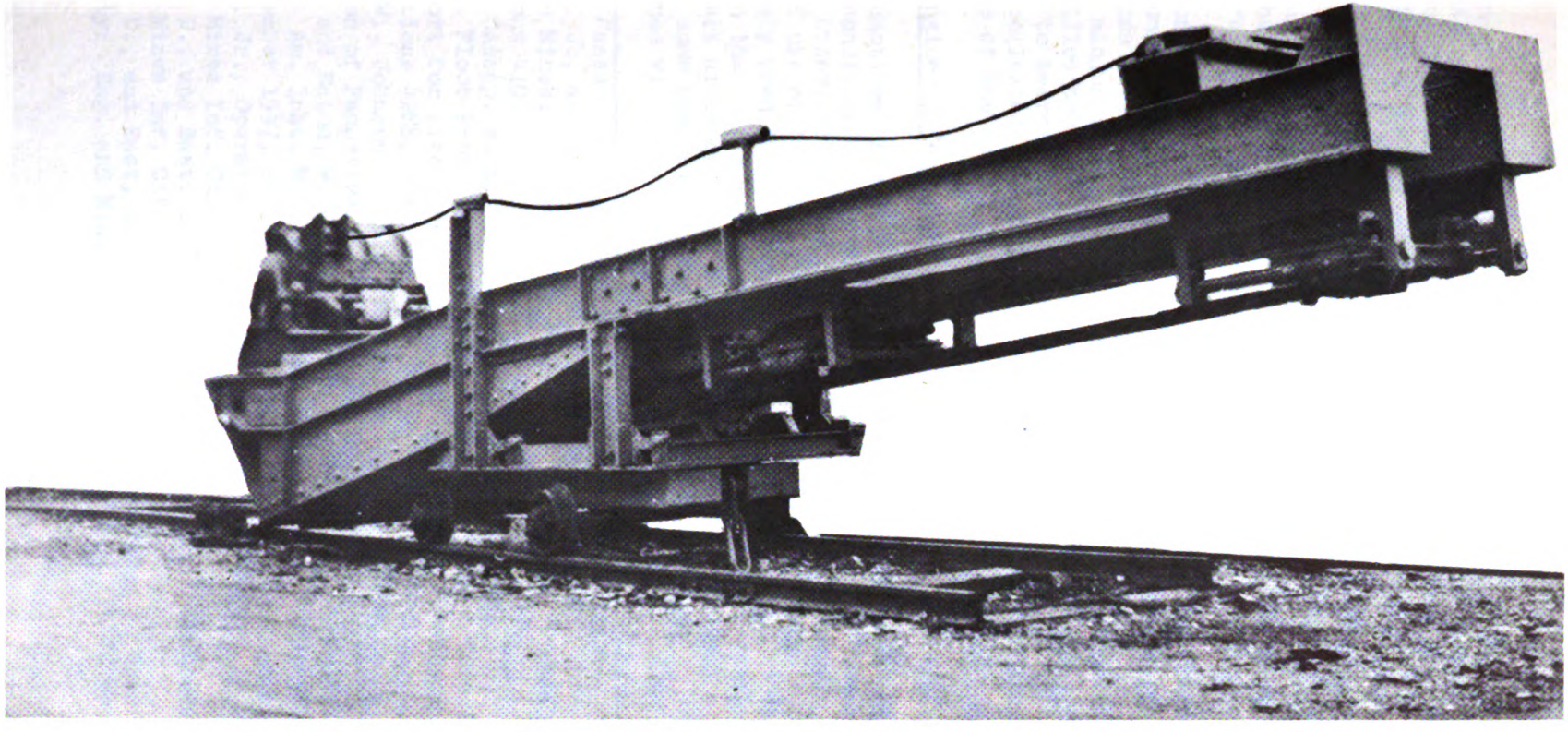

Figure 16. - Bureau of Mines scraper-shaker loading machine.

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(5) infiltration of surface water into underground mine workings.[31, 32] Completion of the investigation of the acid-mine-water problem in the anthracite region revealed that industrial wastes in the streams flowing through the region neutralize the acid water from the mines.[33]

A study of barrier pillars, particularly in the area of the structural saddle in the Northern coal basin, was made to determine the size and condition of the pillars.[34] Various companies were contacted, and information was obtained regarding mine workings, barrier pillars, boreholes, overflow points, and other pertinent information concerning barrier pillars.

One phase of the mine-water problem as it pertains to the northern field of the anthracite region is the presence of the "buried valley" (filled ancient channels) of the Susquehanna River. This valley fill is water-bearing and irregular in trend and depth. The mining companies that have mined under and adjacent to the "buried valley" have drilled thousands of boreholes from the ground surface through the river wash down to bedrock to protect the workers underground and the mine workings. Data are being collected to establish definite limits to this "buried valley" and to study the nature of the material composing the water-bearing valley-fill deposit.

Use of Diesel Engines Underground

Diesel locomotives have been used successfully in European mines for 18 years, but the actual conditions under which they are used have not been publicized in the United States. Observations by Bureau representatives of European practice and a few instances of use of Diesel locomotives in the United States have shown that they can be safely used in both metal and coal mines. Published reports of these studies[35] state that, in European practice, the danger from sparks is eliminated by labyrinth spark arresters and from exhaust fumes by ventilation; adverse State regulations and some prejudices have prevented their adoption in the United States, but improved types will be made that should gain approval.[36, 37]

31/ Ash, S. H., Cassap, W. E., Westfield, J., Eaton, W. L., Romischer, W. M., Podgorski, E. J., and Johnson, L. H., Flood-Prevention Projects at Pennsylvania Anthracite Mines. Progress Report for 1946: Bureau of Mines Rept. of Investigations 4109, 1947, 64 pp.

32/ Ash, S. H., Cassap, W. E., Eaton, W. L., Hughes, K., Romischer, W. M., Westfield, J., Floot-Prevention Projects at Pennsylvania Anthracite Mines. Progress Report for fiscal year ended June 30, 1947: Bureau of Mines Rept. of Investigations 4288, 1948, 51 pp.

33/ Felegy, E. W., Johnson, L. H., and Westfield, J., Acid Mine Water in the Anthracite Region of Pennsylvania: Bureau of Mines Tech. Paper 710, 1948, 49 pp.

34/ Ash, S. H., and Eaton, W. L., Barrier Pillars in the Anthracite Region of Pennsylvania: Am. Inst. Min. and Met. Eng., Tech. Pub. 2289, Class F, Coal Technol., November 1947, 20 pp.

35/ East, J. H., Jr., Operating Diesel Locomotives Underground in European Mines: Bureau of Mines Inf. Circ. 7378, 1946, 13 pp.

36/ Harrington, D., and East, J. H., Jr., Diesel Equipment in Underground Mining: Bureau of Mines Inf. Circ. 7406, 1947, 87 pp.

37/ Harrington, D., and East, J. H., Jr., Diesel Power Can be Used Underground with Safety: Eng. and Min. Jour., vol. 148, No. 6, 1947, pp. 70-76.

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Because of the interest in the application of Diesel engines in coal mines, their use for underground haulage in a clay mine was observed,[38] and tests were made to determine the composition of the exhaust gases produced by the engine under actual haulage conditions and to determine the effects of the operation on the quality of the mine atmosphere.

Studies were completed[39] on the removal of aldehydes from Diesel exhaust gas by scrubbing with an aqueous solution containing sodium sulfite (10 percent by weight) and hydroquinone (0.5 percent by weight). In this process, sodium sulfite is removed by the reaction: $Na_2SO_3 + HCHO + H_2O \longrightarrow NaOH + CH_2 (NaSO_3) OH$. Hydroquinone is added to inhibit the oxidation of sodium sulfite by the residual oxygen in the Diesel exhaust gas.

The results of a full-scale test in which exhaust gas from an engine was passed through approximately 10 gallons of scrubbing solution at a rate of 3,000 cubic feet (at 29.92 inches of Hg and 60° F.) per hour are shown in figure 17. In this test, more than 90 percent of the aldehydes was removed for a period of 20.5 hours. The odor intensity of the raw and scrubbed gas was evaluated by averaging the sense impressions of twelve observers, and the results are presented in figure 18. Since the scrubbed gas was substantially free of aldehydes, the data indicate that the residual odor was caused by some other constituent. This residual odor ranged between faint and very faint and probably would be undetected when the exhaust is diluted with ambient air.

In the test described above, the cost of chemicals for removing aldehydes was 1.5 cents per M cu. ft. of dry exhaust gas (as 29.92 inches of Hg and 60° F.). If it is assumed that an engine produces an average of 5,000 cubic feet of dry exhaust gas per hour and operates continuously for 8 hours a day, the daily cost for chemicals would be about 60 cents.

A series of tests was made using a CFR Diesel engine to determine the effect of cetane number on the composition of the exhaust gas. The results of these tests showed that fuels having low cetane numbers produce slightly more carbon monoxide and aldehydes at the lower fuel : air ratios. However, at intermediate and high fuel : air ratios, cetane number has no significant effect on the production of these constituents. In view of the current difficulty in obtaining the higher-octane fuels, it may be necessary to increase ventilation slightly in underground applications of Diesel engines, particularly if the engine operates under light loads.

For the past several years, the Bureau of Mines has received many requests for information and recommendations on the use of Diesel-powered equipment in noncoal mines and other underground workings, where the material being mined is incombustible and the strata do not liberate combustible gases. To meet these requests, a schedule entitled "Requirements for Approval and Recommendations on the Use of Diesel-Powered Equipment in Noncoal Mines" was drafted.

38/ Berger, L. B., and Artz, R. T., Performance of a Diesel Mine Locomotive: Bureau of Mines Rept. of Investigations 4287, 1948, 15 pp.

39/ Davis, Rogers F., and Elliott, M. A., The Removal of Aldehydes from Diesel Exhaust Gas: Trans. Am. Soc. Mech. Eng., vol. 70, 1948, pp. 745-750.

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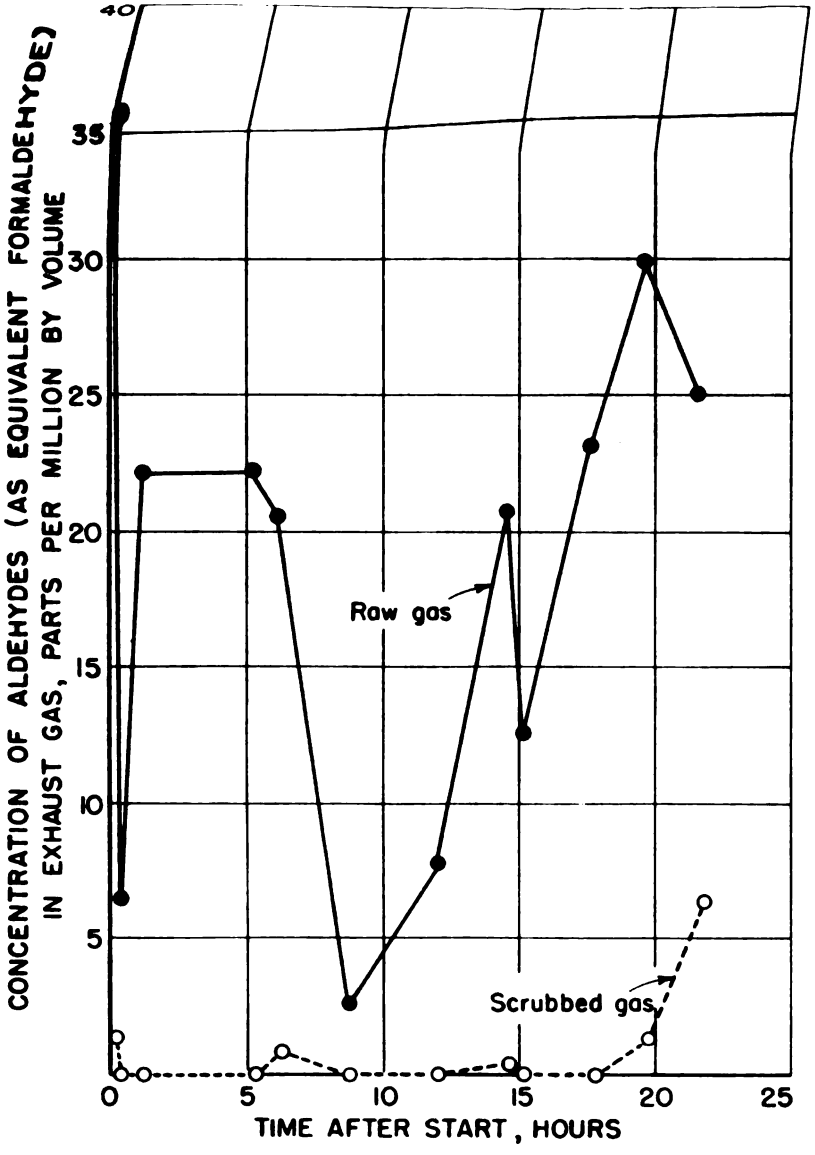

Figure 17. - Variation of aldehyde concentration in raw and scrubbed gas with time.

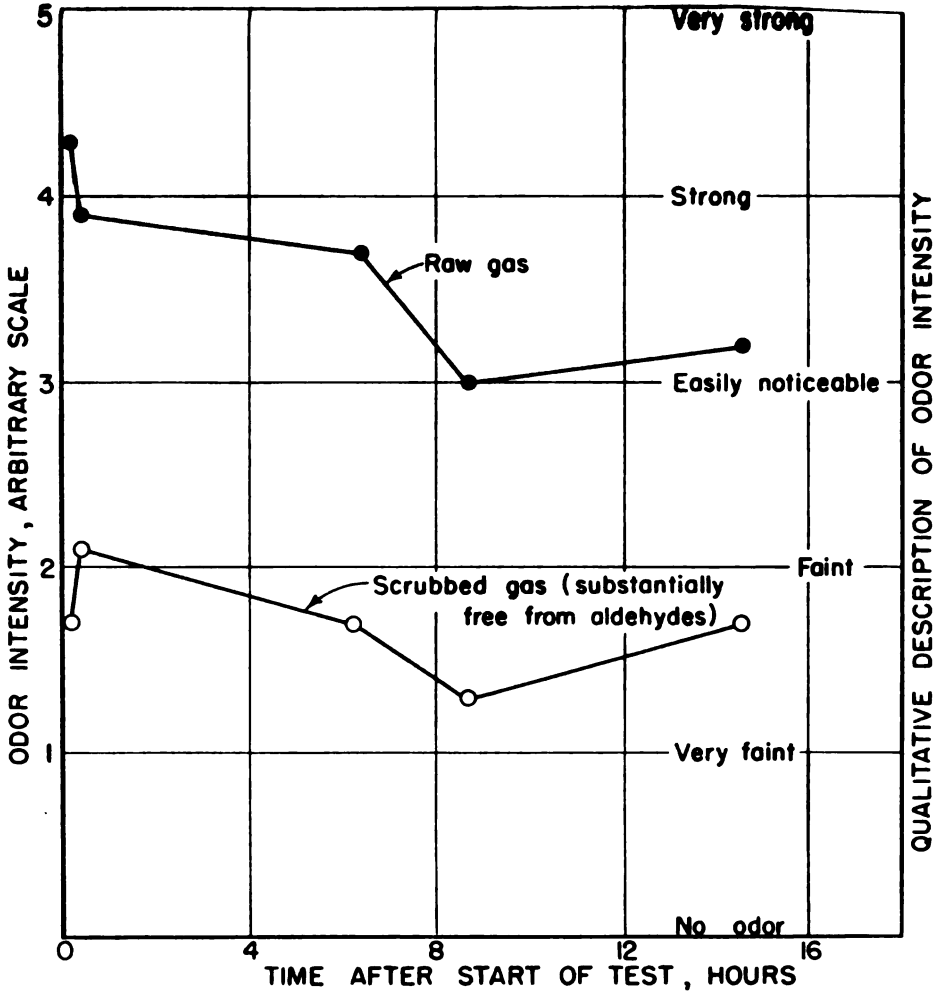

Figure 18. - Variation of odor intensity of raw and scrubbed gas with time.

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Electrical Equipment for Mines

Unless electrical equipment is built, maintained, and used in proper manner in gassy coal mines, that equipment should be regarded as hazardous from the standpoint of initiating mine fires and explosions. As a means of overcoming this hazard, the Bureau of Mines has established certain standards, published as "schedules" to guide manufacturers who produce mine equipment. Equipment that passes the tests and inspections prescribed by these standards is formally approved and becomes known as "permissible" equipment, that is, permissible for use in gassy coal mines. The schedules are amended from time to time as the need arises for changing safety standards. Thus, an amendment[40] to Schedule 2E established tests to bring about the development of trailing cables resistant to propagation of flame. In the past, overloaded or short-circuited cables of portable mine equipment have caught fire and then set the mine on fire. Cables passing the newly established tests will reduce this fire hazard.

Under the eight schedules now in effect, a manufacturer can have nearly every type of equipment used at or near the face of active mine workings investigated for its liability to ignite gas or coal dust or a combination of these. During the fiscal year 1948, 55 approvals were issued. These included 19 loading machines and conveyors, 4 cutting machines, 3 drilling machines, 5 mining machine trucks, 2 air compressors, 3 battery-operated shuttle cars, 1 post puller, 1 timbering machine, 1 fan-drive unit, 1 greasing truck, 1 battery-operated utility truck, 2 pumps, 1 storage-battery locomotive, 5 10-shot blasting units, 3 junction boxes, 1 distribution box, 1 flame safety lamp, and 1 flashlight.

In order to keep safety engineers, mine inspectors, and officials informed as to the number and variety of equipment that has been approved by the Bureau of Mines, classified lists[41, 42] are published periodically.

Electrical Hazards in Coal Mines

Consumption of electric power in bituminous-coal mining has increased continuously since its introduction for haulage purposes about 1887. The use of electric power has been accompanied by numerous hazards and in many respects safe practices have not been adopted as rapidly as applications of electric power have spread. The Bureau has made studies and investigations of practices and equipment connected with use of electric power in coal mines with deep concern for the growing dangers from electric shock, fires and explosions. Safer methods of use and numerous devices for guarding against these hazards have been devised. Engineers of the Health and Safety Branch are engaged in explaining these safety measures and urging their

40/ Bureau of Mines, Amendment to Schedule 2E, Procedure for Testing Junction Boxes and Electric Motor-Driven Mine Equipment for Permissibility: Approved Oct. 21, 1947, 4 pp.; duplicated from Federal Register, vol. 12, No. 219, Nov. 7, 1947, pp. 7285-7287.

41/ Hooker, A. B., Permissible Equipment Approved to Jan. 1, 1947, with Appended List of Available Flame-Lamp Fuels: Bureau of Mines Inf. Circ. 7432, 1947, 44 pp.

42/ Hooker, A. B., Permissible Mine Equipment Approved During the Calendar Year 1947; Supplement to I. C. 7432: Bureau of Mines Inf. Circ. 7465, 1948, 5 pp.

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adoption in all coal mines.[43] One of the greatest hazards is the bare trolley wire now an outstanding source of mine fires and electrocutions. Makeshift installations and repairs of machinery and circuits are other serious faults whose danger is commonly overlooked.

Mine-Communication Apparatus

Emergency mine-communication apparatus having a primary objective of locating men trapped in mines after fires and explosions, was developed further and tested under varying conditions in an iron mine and a salt mine as well as in anthracite and bituminous coal mines.[44, 45] In one mine, satisfactory two-way radio communication over the power distribution system was established through a distance of 2-1/2 miles. Satisfactory two-way communication through the ground was achieved through distances up to 1,050 feet in another mine. This distance probably can be increased by improvement in the radio equipment.

Toxic Mine Atmospheres

In connection with requirements of the Federal Coal Mine Inspection Act, approximately 15,000 gas and dust samples were analyzed, which required more than 100,000 individual determinations. These samples were analyzed to determine the presence of dangerous or unhygienic conditions. Where undesirable conditions were found, recommendations were made to eliminate or improve them.

To assist operators in providing better working conditions, information was presented on laboratory equipment for the analysis of mine atmospheres[46] and on determination of carbon monoxide[47] and sulfur dioxide.[48] Information was presented[49] on the interpretation of analytical results in relation to the maximum allowable concentration of toxic substances permitted in the air of working places. A report was published describing a mine-air-conditioning chart to provide for the rapid determination of psychometric data and for the rapid solution of air-conditioning problems of major interest to the mining industry.[50]

43/ Bureau of Mines, Electrical Accidents at Bituminous-Coal Mines, Coal-Mine Accident Prevention Course - Section 6: Miners' Circ. 59, 1947, 70 pp.

44/ Coggeshall, E. J., Felegy, E. W., and Harrison, L. H., Some Studies of Emergency Mine Communications: Bureau of Mines Rept. of Investigations 4135, 1948, 44 pp.

45/ Felegy, E. W., and Coggeshall, E. J., Applicability of Radio to Emergency Mine Communications: Bureau of Mines Rept. of Investigations 4294, 1948, 56 pp.

46/ Berger, L. B., and Schrenk, H. H., Laboratory Equipment for the Analysis of Mine Atmospheres: Bureau of Mines Inf. Circ. 7441, 1948, 18 pp.

47/ Berger, L. B., Determination of Carbon Monoxide by Absorption in the Haldane-Type Gas-Analysis Apparatus: Bureau of Mines Rept. of Investigations 4187, 1947, 6 pp.

48/ Pearce, S. J., and Schrenk, H. H., Determination of Sulfur Dioxide in Air by Means of the Midget Impinger: Bureau of Mines Rept. of Investigations 4282, 1948, 6 pp.

49/ Schrenk, H. H., Interpretation of Permissible Limits in the Breathing of Toxic Substances in Air: Bureau of Mines Inf. Circ. 7457, 1948, 7 pp.

50/ McElroy, G. E., A Mine Air-Conditioning Chart: Bureau of Mines Rept. of Investigations 4165, 1947, 23 pp.

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To aid in the selection of respiratory protective devices, a list of such equipment approved by the Bureau of Mines was published.51/

The introduction of new products often is accompanied by new hazards. The introduction of the many new synthetic resins raises the question as to possible toxic gases that might be produced when such materials are burned or thermally decomposed. A report describing the various toxic gases produced under laboratory conditions was published.52/

New types of breathing apparatus were tested under the Bureau schedule of permissibility to insure that the use of such equipment in dangerous atmospheres would not endanger the lives of the wearers and to determine the limitations of the new equipment.53/

Safety and Efficiency in Coal Mining

The high rate of accidents from falls of roof is accompanied by loss of production due to interruptions at the working faces. Experiments on suspension supports are being conducted at several mines to determine if they can be used as effectively in the coal mines as in the lead-zinc mines of the Tri-State District.54, 55/

In cooperation with the State mine officials, a study is being made in Washington coal mines of methods for extinguishing mine fires by using dry ice.

A bibliography of Bureau of Mines publications dealing with health and safety was prepared for the conveniences of the mineral industry.56/

Barricading as a Life-Saving Measure

The value of barricading methods has long been recognized after mine explosions and during mine fires where deadly gases spread through the workings and imperil the men who survive. In 1923 Miners' Circular 23 was issued to give information on instances of actual barricading by trapped men, so that others would be familiar with effective methods in an emergency. This circular was revised and brought up to date in 1941 and again in 1946.57/ This study of experiences to the present shows that a

51/ Schrenk, H. H., List of Respiratory Protective Devices Approved by Bureau of Mines: Bureau of Mines Inf. Circ. 7444, 1948, 14 pp.

52/ Berger, Lawrence B., Schrenk, H. H., Gale, James A., Stewart, Ralph W., and Sieffert, Lorenz E., Toxicity and Flame Resistance of Thermosetting Plastics: Bureau of Mines Rept. of Investigations 4134, 1947, 11 pp.

53/ Grove, G. W., and Quenon, E. E., Approval of Newly Developed Self-contained Breathing Apparatus, Instructions in its Care and Use: Bureau of Mines Inf. Circ. 7413, 1947, 18 pp.

54/ Thomas, E., Suspension Roof Support for Coal-Mine Roadways: Coal Age, vol. 53, No. 7, 1948, pp. 86-88.

55/ Thomas, E., Seeling, C. H., Perz, F., and Hansen, M. V., Suggested Roof Supports for Use at Faces in Conjunction with Mechanical Loading: Bureau of Mines Inf. Circ. 7471, 1948, 9 pp.

56/ Davenport, S. J., Bibliography of Bureau of Mines Publications Dealing with Health and Safety in the Mineral and Allied Industries, 1910-46: Bureau of Mines Tech. Paper 705, 1948, 154 pp.

57/ Harrington, D., and Fene, W. J., Barricading as a Life-Saving Measure in Mine Fires and Explosions: Bureau of Mines Miners' Circ. 42 (revised Dec. 1946) 1948, 80 pp.

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tight stopping usually can be erected in a suitable place in 30 minutes to a few hours. Air circulation in the area outside the barricade should be short-circuited, and a large enough area should be enclosed to provide at least 1,000 cubic feet of air per man and as much more as can be readily enclosed.

Coal-Mine Disasters

After rescue and recovery work at coal-mine disasters during the year engineers and inspectors of the Health and Safety Branch made investigations and prepared reports on the causes of these disasters with recommendations for protection from the hazards shown.58/ In the fiscal year 1947, 17 mine explosions, causing 154 deaths, were reported; of these, 4 were major disasters (loss of 5 or more lives at a time), causing a total of 144 deaths. One explosion in Illinois killed 111 persons; the cause was unsafe blasting practices, coupled with utterly inadequate rock dusting. An explosion in Indiana, resulting in 8 deaths, also was found to have been caused by unsafe blasting and failure to apply rock dust to the active workings. Two gas explosions in Pennsylvania anthracite mines caused the loss of 25 lives; the primary cause in both instances was laxity in testing for methane.

Miscellaneous Causes of Coal-Mine Injuries

A study of various supposedly minor causes of coal-mine accidents shows that the total of injuries from machinery, flying particles, steam, compressed air, stumbling, falls of persons, hand tools, and other causes amount to about 45 percent of all coal-mine injuries. A detailed discussion of such hazards with recommended protective measures has been compiled and published for use in teaching classes of accident prevention for mine officials.59/ Numerous safe practices are discussed in addition to the over-all problems of supervision, inspection, formulation of safety rules, and the education and training of workers.

Gaseous Explosions and Use of Explosives

Permissibility Tests

The conditions and requirements governing the chemical and physical testing of explosives to determine their characteristics so that they can be used safely in gassy and dusty coal mines are set forth in Schedule 1F.60/

Four samples of explosives were submitted to determine their safety for use in gassy and dusty coal mines. Two of these passed the required tests for permissibility and two were withdrawn from use.

Twenty-three samples of explosives containing TNT and ammonium nitrate were tested for possible use as permissible explosives. All samples failed to pass the gallery tests.

58/ Harrington, D., Fene, W. J., and Humphrey, H. B., Coal-Mine Explosions and Coal- and Metal-Mine Fires in the United States during the Fiscal Year Ended June 30, 1947: Bureau of Mines Inf. Circ. 7456, 1948, 21 pp.

59/ Bureau of Mines, Miscellaneous Accidents in Bituminous-Coal Mines, Section 7, Coal-Mine Accident Prevention Course: Miners' Circ. 60, 1947, 85 pp.

60/ Bureau of Mines, Procedure for Testing Explosives (Including Sheathed Explosives) and Blasting Devices for Permissibility and Suitability: Sched. 1F, approved Jan. 20, 1945, 11 pp., with amendments approved Mar. 14 and Aug. 7, 1945, June 24, 1946, and Feb. 27, 1948.

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On June 30, 1948, the permissible list[61] contained the names of 191 explosives and 9 blasting devices compared with 186 explosives and 9 blasting devices on the list as of June 30, 1947.

Field Samples of Permissible Explosives

A permissible explosive or blasting device, after approval for use in gassy and dusty coal mines, must be so manufactured that it will have all the chemical and physical characteristics of the basic sample. To check on their quality, 28 samples of permissible explosives were collected from the manufacturers' magazines. Two samples failed to pass the gallery tests and several others did not meet the established tolerances for some of their physical characteristics. The items in which these explosives failed and the number of failures, respectively, were as follows: Physical examination, 7; chemical analysis, 10; rate of detonation, 7.

Consumption of Permissible Explosives

During the fiscal year 1948 the consumption of permissible explosives in coal mines totaled approximately 116 million pounds. In addition to this, approximately 33 million pounds of black blasting powder and approximately 136 million pounds of high explosives were used, the last chiefly in strip-mining operations. Thus, three and one-half times as much permissible explosives as black blasting powder were used. During the past few years, the quantity of permissible explosives used has increased, whereas the quantity of black blasting powder used has remained almost the same.

Vibrator-Type Multiple-Shot Blasting Unit

To meet the need for a satisfactory permissible multiple-shot blasting unit, which would be capable of firing 10 detonators in series and be safe for use in underground mining where a gas ignition hazard may exist, the Bureau developed a capacitor-battery type.[62] It is based upon utilization of the discharge energy from a capacitor charged to a given voltage and having capacitance adequate to store enough energy to initiate 10 detonators in series. The primary source of energy is a 4-volt cap-lamp battery and the voltage is built up to the required value by means of a vibrator.

To operate safely in gassy atmospheres, the voltage on the capacitor in the unit must be reduced to such a value that dangerous sparking resulting from breakage of the firing circuit does not occur after movement of the coal face has possible released gas. The present unit has been found to be safe in this respect. The experimental model has been operated hundreds of times during test work and has performed satisfactorily.

Extinction of Isobutane Flames by Carbon Dioxide and Nitrogen

Recently, isobutane has become a commercially important raw material in the production of aviation gasoline by the alkylation process, in which isoparaffins are

61/ Tiffany, J. E., and Gaugler, Z. C., Active List of Permissible Explosives and Blasting Devices Approved Previous to December 31, 1945: Bureau of Mines Rept. of Investigations 3910, 1946, 20 pp.

62/ Gibson, F. C., and Brown, F. W., Vibrator-Type Multiple-Shot Blasting Unit: Bureau of Mines Rept. of Investigations 4136, 1947, 5 pp.

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combined with olefins to give higher molecular weight compounds of branched-chain structure. Therefore, the general explosion hazards of this substance have been determined.63/

The lower and upper limits of inflammability of isobutane in air were found to be 1.83 and 8.43 percent by volume, respectively.

Tests were carried out with isobutane-air mixtures to which increasing proportions of nitrogen or carbon dioxide were added both in the lower- and upper-limit ranges. The concentrations of these gases were increased eventually to the point where the mixtures became noninflammable when mixed with air in any proportions. Figure 19 shows the total areas of inflammability of isobutane-air-nitrogen and isobutane-air-carbon dioxide mixtures. It is seen that the addition of nitrogen to isobutane-air mixtures in the lower-limit range has virtually no effect upon the limit of inflammability. On the other hand, the addition of nitrogen in the upper-limit range decreases the limit progressively almost in direct proportion to the amount of nitrogen. When the mixture contains 39.8 percent of added nitrogen, the lower and upper limits of inflammability merge, and further additions of nitrogen produce mixtures that are entirely noninflammable. This point is reached when 26 percent of carbon dioxide is present in the mixture.

Effects of Hydrocarbons and Other Gases Upon the Explosibility of Acetylene

There is considerable interest at present in the safe handling of acetylene under pressure. The maximum permissible pressure in portable acetylene generators is 15 pounds per square inch gage. Tests by the Bureau of Mines have shown that this pressure is too high to prevent explosions of gaseous acetylene in the absence of air. In fact, dry acetylene gas can be exploded at pressures greater than 5.9 pounds per square inch gage. It was found that the addition of hydrocarbons such as natural gas, propane, or butane to acetylene rendered the latter less explosive. The effectiveness was found to increase with the molecular weight of the hydrocarbon. For example, at 15 pounds gage pressure, the percentage of hydrocarbon required to be present in the acetylene to prevent explosion is as follows: Natural gas, 13.8 percent; propane, 9.2 percent; butane, 8.4 percent by volume.

It seemed desirable to determine the inhibiting effects of these hydrocarbons at pressures up to 100 pounds gage.64/ The amounts required to prevent explosions of acetylene at different pressures are shown in table 4. The efficiency of the added hydrocarbons is thus seen to increase with increasing molecular weight.

For comparison, additional experiments were carried out with carbon dioxide, nitrogen, helium and hydrogen with results shown in table 5. It is seen that the inhibiting effects of these gases, except carbon dioxide, are low compared with the hydrocarbons and that there is little difference in the effects of nitrogen, helium, and hydrogen. Carbon dioxide is comparable to natural gas.

These results are shown graphically in figure 20.

63/ Jones, G. W., and Scott, G. S., Extinction of Isobutane Flames by Carbon Dioxide and Nitrogen: Bureau of Mines Rept. of Investigations 4095, 1947, 9 pp.

64/ Jones, G. W., Kennedy, R. E., and Spolan, I., Effect of Hydrocarbons and Other Gases Upon the Explosibility of Acetylene: Bureau of Mines Rept. of Investigations 4196, 1948, 8 pp.

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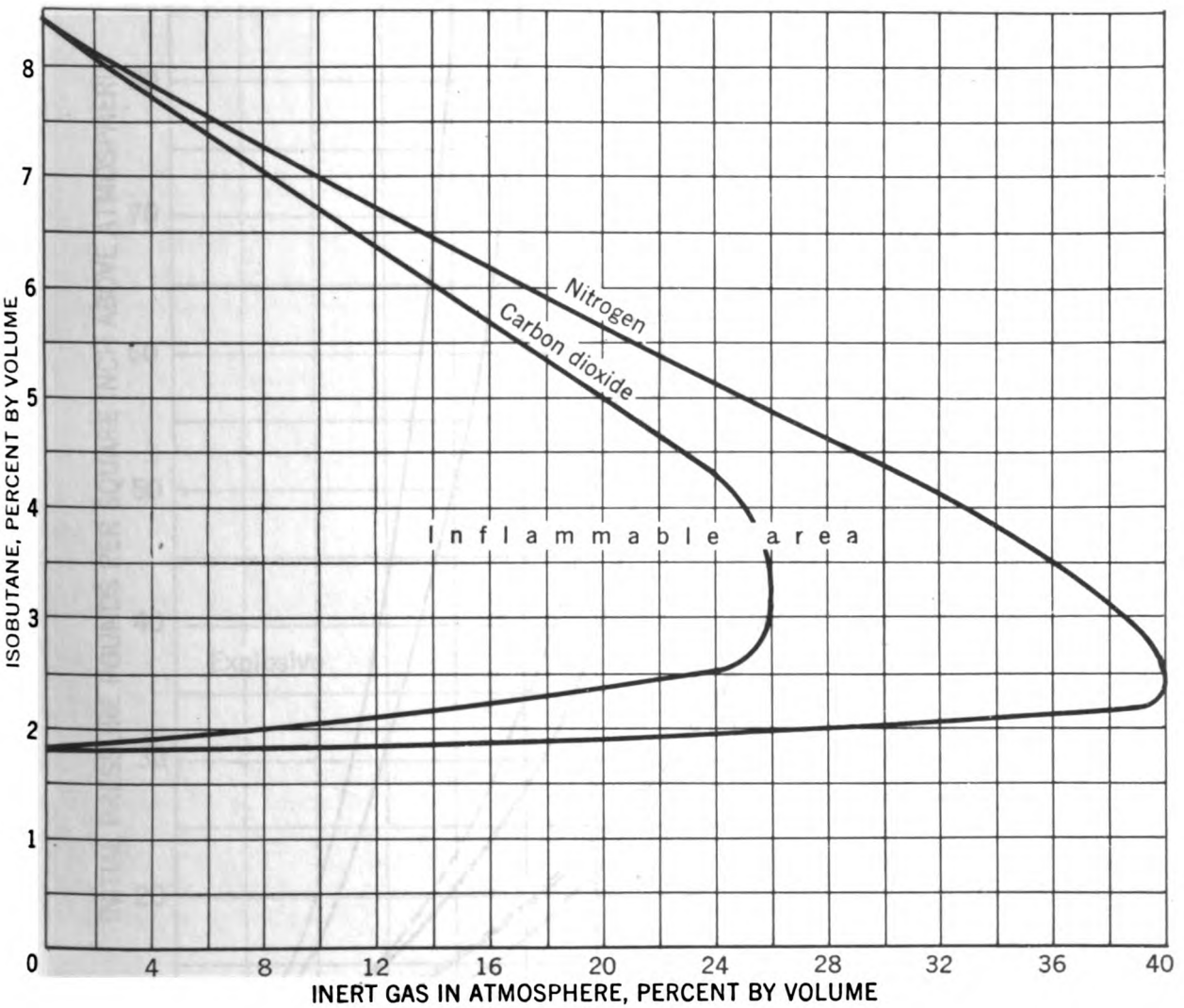

Figure 19. - Limits of inflammability of isobutane in air, nitrogen, and carbon dioxide atmospheres.

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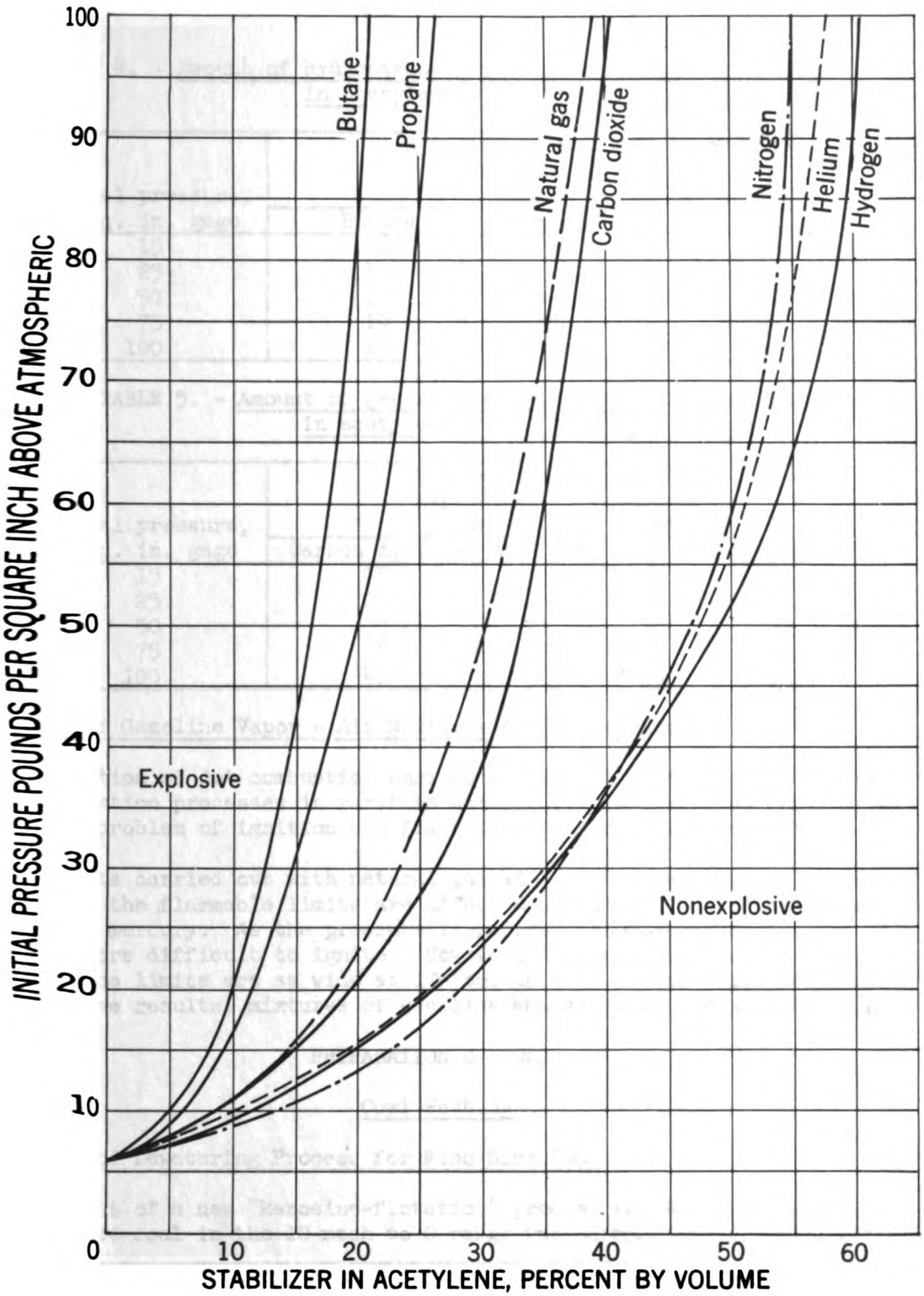

Figure 20. - Effect of pressure on the explosibility of acetylene-hydrocarbon and acetylene-gas mixture.

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TABLE 4. - Amount of hydrocarbon required to prevent explosions in acetylene at different pressures

Initial pressure, lb./sq. in. gage	Hydrocarbon required to prevent explosion in acetylene, percent by volume		
	Butane	Propane	Natural gas
15	8	10	15
25	11	13	21
50	17	20	31
75	19	24	36
100	21	26	39

TABLE 5. - Amount of gas required to prevent explosions in acetylene at different pressures

Initial pressure, lb./sq. in. gage	Gas required to prevent explosions in acetylene, percent by volume			
	Carbon dioxide	Nitrogen	Helium	Hydrogen
15	15	23	19	19
25	23	32	31	31
50	33	47	48	49
75	38	53	55	58
100	41	55	58	61

Flammability of Gasoline Vapor - Air Mixtures at Low Pressures

The operation of jet combustion engines at high altitudes and the general aspects of combustion processes in rarefied atmospheres have created considerable interest in the problem of ignition and flame propagation at low pressures.

Experiments carried out with natural gas-air mixtures at reduced pressures showed[65] that the flammable limits are affected but little at reduced pressures down to 75 mm. mercury. As the pressure is reduced below atmospheric, the mixtures become more difficult to ignite. However, if a suitable source of ignition is employed, the limits are as wide at 175 mm. as they are at atmospheric pressure. In view of these results, mixtures of gasoline and air were investigated similarly.[66]

PREPARATION OF COAL

Coal Washing

New Cleaning and Dewatering Process for Fine-Size Coal

Development of a new "kerosine-flotation" process for the cleaning and dewatering of fine-size coal in the 10-mesh to 0 range was carried to the commercial

[65] Jones, G. W., and Kennedy, R. E., Inflammability of Natural Gas: Effect of Pressure upon the Limits: Bureau of Mines Rept. of Investigations 3798, 1945, 13 pp.

[66] Jones, G. W., and Spolan, I., Inflammability of Gasoline Vapor-Air Mixtures at Low Pressures: Bureau of Mines Rept. of Investigations 3966, 1946, 5 pp.

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stage.[67] During the past year a commercial-scale plant using this process was installed at one of the mines in the Birmingham, Ala., district. Since its installation, this plant has been producing about 100 tons per day of excellent-grade, cleaned and dewatered coal from a dewatering-screen underflow which was formerly too high in ash to be suitable for use as coking coal. The feasibility of using the process at several other plants is being investigated. Prospects for making the process applicable to the treatment of fine-size raw coal are very encouraging; and, if it can be adapted to this purpose, it is believed that it will be a practical solution to many of the sludge and slurry problems with which the coal-preparation industry is confronted. Furthermore, it should serve to increase considerably the recovery of coking coal throughout the industry.

New Machine for Thickening Coal Slurry

A cyclone device employed to thicken the loess suspension in the loess heavy-medium coal-cleaning process developed by the Netherlands State Mines has been studied by the Bureau of Mines after one of its staff observed its operation in the Netherlands in 1945. The first experimental work with the cyclone conducted by the Bureau was an investigation of the unit functioning as a heavy-medium cleaner for fine coal. Further investigation dealt exclusively with operation of the cyclone as a thickener of coal slurries - a new application of this device that promises wide usefulness under American conditions.

Figure 21 illustrates the construction of one of the cyclones used in this investigation. In operation the slurry of water and fine coal is pumped through the tangential feed nozzle and thereby caused to rotate or whirl. Under the influence of the centrifugal force developed by the rotary motion, the solid particles are thrown to the wall of the conical section and forced downward along the wall until they pass out of the cyclone through the underflow or bottom opening. The water, largely freed of solid particles, overflows through the central opening in the orifice plate at the top and leaves the cyclone by way of the overflow chamber.

Figure 22 is a photograph of the laboratory installation. The cyclone is mounted over a 50-gallon conical tank, which serves as a collecting sump for the feed pump. Thus the cyclone is in a closed circuit, both overflow water and underflow coal falling directly into the conical tank and from there being recirculated through the cyclone. The centrifugal pump is provided with a variable-speed drive capable of developing from 0 to 50 psi pressure at the feed nozzle of the cyclone.

Table 6 presents the results of two tests made on the same slurry with identical cyclone adjustments; in test 82 the underflow was a vortex, while for test 81 the underflow was converted to sausage form. In the test made with vortex operation 12.3 percent of the water present in the feed entered the underflow product, and the underflow contained 59.4 percent solids. A sausage-type underflow always contains more solids than does a vortex underflow.

67/ Gandrud, B. W., and Riley, H. L., A Combination Cleaning and Dewatering Process for Treating Fine Sizes of Coal. Preliminary Report: Bureau of Mines Rept. of Investigations 4306, 1948, 25 pp.

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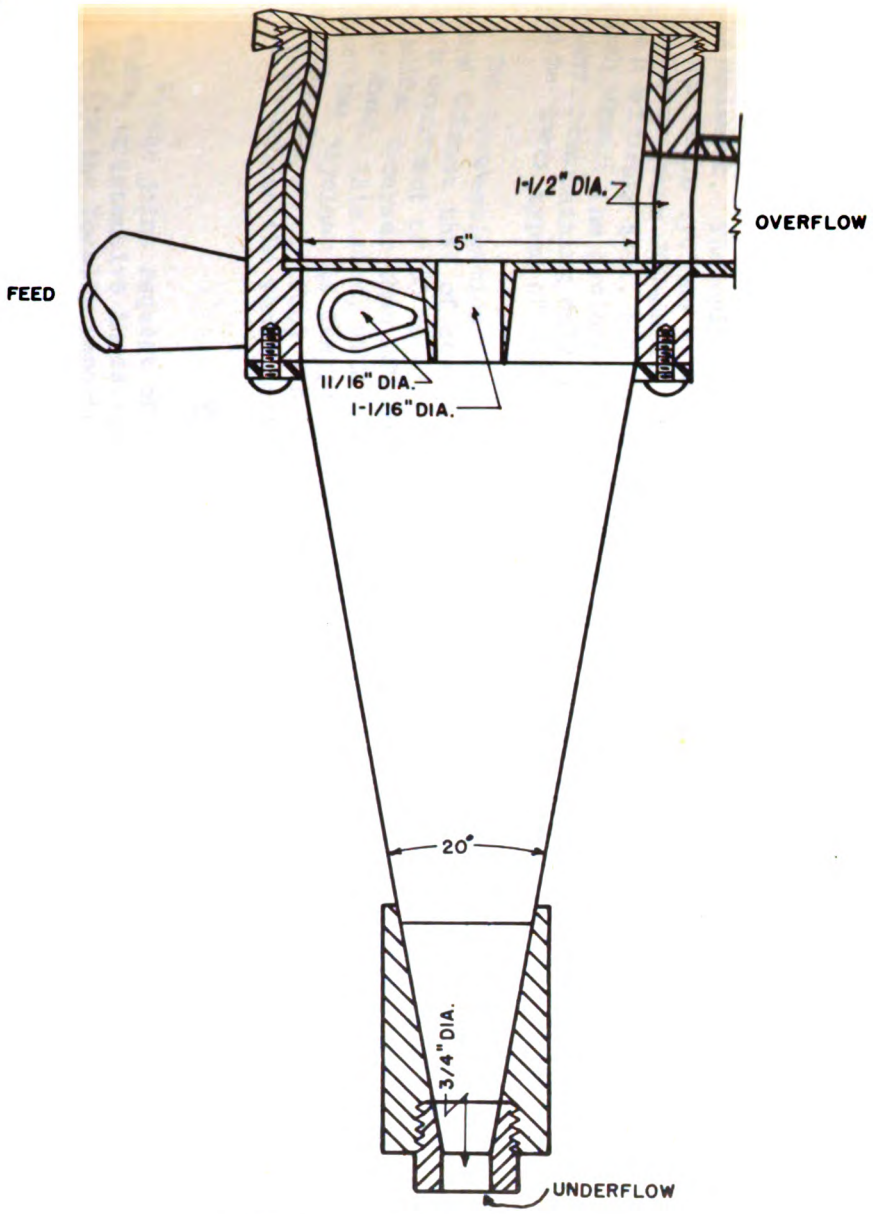

Figure 21. - Construction of cyclone.

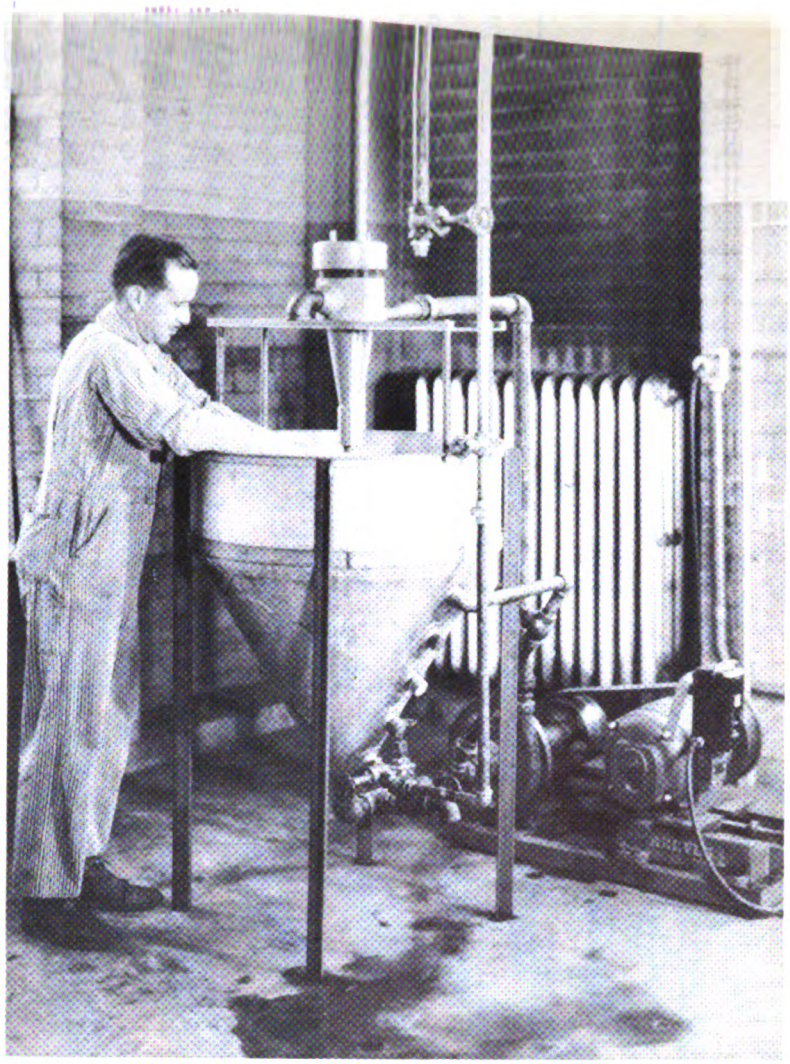

Figure 22. - Cyclone test unit arranged for closed-circuit operation.

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TABLE 6. - Comparison of cyclone operation with vortex- and sausage-type underflows

	Test 82, vortex-type underflow			Test 81, sausage-type underflow		
	Feed	Over-flow	Under-flow	Feed	Over-flow	Under-flow
Solids, percent	8.0	0.8	39.5	8.0	1.0	59.4
Distribution of total solids, percent	100.0	7.7	92.3	100.0	10.8	89.2
Distribution of water, percent	100.0	87.7	12.3	100.0	94.7	5.3
Screen analysis of solids, percent:						
35 to 48	24.4	.0	26.4	23.8	.0	26.7
48 to 65	12.7	.0	13.8	20.0	.0	22.4
65 to 100	23.5	.1	25.5	19.2	.1	21.5
100 to 150	9.1	.0	9.8	9.4	.0	10.5
150 to 200	9.6	.4	10.4	8.6	.8	9.6
200 to 270	2.6	.2	2.8	2.6	1.5	2.7
270 to 400	4.6	1.1	4.9	4.4	8.2	3.9
Under 400	13.5	98.2	6.4	12.0	89.4	2.7
Distribution of solids by sizes, percent:						
35 to 48	100.0	.0	100.0	100.0	.0	100.0
48 to 65	100.0	.0	100.0	100.0	.0	100.0
65 to 100	100.0	.0	100.0	100.0	.0	100.0
100 to 150	100.0	.0	100.0	100.0	.0	100.0
150 to 200	100.0	.3	99.7	100.0	1.0	99.0
200 to 270	100.0	.8	99.2	100.0	6.2	93.8
270 to 400	100.0	1.7	98.3	100.0	20.4	79.6
Under 400	100.0	56.1	43.9	100.0	80.0	20.0

The figures at the bottom of table 6 show the percentage of each size fraction of the solids entering the overflow water and the percentage recovered in the underflow product. The only noticeable difference in the recovery of solids obtained in operating the cyclone with sausage- and vortex-type underflows occurs in the material finer than 200-mesh. There was virtually no loss of solids coarser than 200-mesh in either test, but the material finer than this size was recovered more efficiently when the cyclone was operated with a vortex underflow. However, in treating a slurry containing only a moderate quantity of extreme fines the recovery obtained with the two types of underflows is substantially the same.

The investigation of the cyclone demonstrated that its capacity is several hundred times that of conventional thickeners. Coal slurries can be thickened to a solids content of 60 to 65 percent. The cyclone effects virtually complete recovery of solids coarser than 200-mesh but recovers only about one-third of the material finer than this size, with a resultant inability to produce a clear overflow water. Since the cyclone is inexpensive to construct, has no moving parts, and is cheap to operate, it should find a number of applications, not only in the coal-washing field, but throughout the whole mineral industry.

Washing Tests of Oregon Coal

At the joint request of the Municipal Water Board, Eugene, Oreg., and coal-land owners, an intensive investigation was made of the washing characteristics of a coal from the locally important Beaver Hill bed, Coos County, Oreg., with the ultimate object of supplying fuel for a proposed coal-burning steam-electric power plant,

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constructed at the mine mouth, to relieve the shortage of electric power in the area. One of the questions upon which the proposal hinged was that of the quality of the washed coal that could be delivered by the mine. Although coal has been washed at the mine for the past few years, it was not felt that the mill performance was indicative of what could be expected from a modern washery.

A 12-ton sample of coal from the Southport mine was crushed to pass a 2-inch square-hole screen and washed in a laboratory-size, 3-cell, 1-compartment, Baum-type jig which has a capacity on this coal of about 5 tons per hour. Samples of the raw coal and of all jig products were subjected to float-and-sink tests and ash analyses to permit evaluation of the laboratory jig performance in terms of full-scale plant operation.

The yield of washed coal in terms of the jig feed was 83.2 percent; and, taking into account the 5.1 percent of rock picked out at the mine, the washed-coal yield was 79.0 percent of the original raw coal. The washed coal contained 11.0 percent ash, moisture-free basis, which is equivalent to 10.0 percent ash on a bed-moisture basis. The heating value of the coal was 9,760 B.t.u. per pound on a bed-moisture basis or 11,650 B.t.u. on a moisture-free basis.

Washing Tests of Alabama Coal

Washability studies[68] of coals from the Clark and Gholson beds at Boothton, Ala., indicated that, if the coals were washed separately in plants combining jigs and tables, the Gholson bed should give a 4-inch to 0 washed coal of about 3.7 percent ash and the Clark, a 4-inch to 0 washed coal of about 6.4 percent ash. The yields of washed coal depend largely on the amount of rock introduced into the run-of-mine coal during mining operations. On the basis of the run-of-mine samples used in this washability study, the Gholson bed would give a yield of about 86.9 percent of the feed to the washer as washed coal. The corresponding figure for the Clark bed would be about 68.7 percent of the washer feed as washed coal. Analyses of seam samples showed that both coals have a low-sulfur content.

Preparation Characteristics of Maryland Coals

A comprehensive survey of the preparation characteristics of American coals was initiated by publication of data on Maryland coals.[69] Sizing tests and float-and-sink tests of representative samples of the minable coal beds in the Georges Creek, Upper Potomac, and Castleman Basins indicated that some of these older beds, below the Pittsburgh, can be made suitable for use in coking-coal blends with high-volatile coals. Others of these beds, not now fully developed, could be prepared for efficient industrial and domestic fuel.

The Kittanning beds respond best to washing. Treatment of these coals by conventional washing processes could produce a grade of coal up to current metallurgical standards with respect to sulfur and ash content. In some areas the Lower Bakerstown and Mount Savage beds would yield a low-sulfur product by washing, but careful selection of mining areas and treatment facilities would be necessary. All of these coals respond favorably to fine crushing to free the product of associated impurities.

68/ Gandrud, B. W., and Riley, H. L., Washability Study of the Clark and Gholson Coal Beds at Boothton, Ala.: Bureau of Mines Rept. of Investigations 4160, 1947, 11 pp.

69/ Crentz, W. L., and Fraser, Thomas, Preparation Characteristics of Maryland Coals: Bureau of Mines Tech. Paper 701, 1947, 66 pp.

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Figure 23. - Principle coal-producing fields of South America.

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The Upper Bakerstown bed can be improved by washing, but the top bench would have to be discarded in many cases. A washed coal analyzing less than 8 percent ash and 1.5 percent sulfur can be obtained by washing at commercial gravities.

The Lower Bakerstown and Upper Freeport beds are amenable to washing if the operation is restricted to the bottom bench in each instance.

Preparation Characteristics of Certain Peruvian Coals

A study of preparation characteristics of the anthracites in the Santa River Valley of Peru[70] disclosed that extensive minable deposits of anthracite available through the Pacific coast port of Chimbote in northern Peru can be prepared to form a high-grade domestic and steam coal suitable to the South American trade and to users of special fuels on the Pacific coast of the United States.

A somewhat related source of low-volatile coking coal occurs in the Oyon[71] coal field northeast of Lima. Washability and coking tests indicated that the coal from several deposits in this general area, high on the western slope of the Continental Divide in the district of Cajatambo, is suitable for blending with high-volatile coking coals of the Sunnyside, Utah, type to improve the coke structure. Float-and-sink tests of a sample of the coal showed it to be readily responsive to mechanical cleaning. A prepared product of 5.0 percent ash and 0.90 percent sulfur can be obtained by treating the coal represented by this sample. Carbonization tests of the Oyon coal made in the 13-inch BM-AGA retort at 900° C. gave the following yields of products: Coke, 83.7 percent; gas, 10,200 cubic feet per ton of coal; tar, 4.7 gallons per ton; light oil, 1.27 gallons per ton; and ammonium sulfate, 8.7 pounds per ton.

In connection with cooperative Latin American Projects, of which the above surveys were a part, a brief general survey of coal resources and activities was prepared for the Pan American Institute of Mining Engineering and Geology.[72] Figure 23 shows the principal coal-producing fields of South America.

Upgrading of Marginal Coking Coals

Upgrading of marginal coking coals by preparatory treatment is designed to extend the supply of metallurgical fuel. One of the most promising directions for research is the reduction of the sulfur content of high-sulfur coals that are otherwise adapted to coking. This is especially important in the United States because of the large reserves of coking coal in the Pittsburgh area that are too high in sulfur to meet current specifications.

70/ Fraser, Thomas, Preparation Characteristics of Anthracites in the Santa River Valley, Peru: Bureau of Mines Rept. of Investigations 4200, 1948, 31 pp.

71/ Fraser, Thomas, and Davis, J. D., Preparation and Carbonization Characteristics of Low-Volatile Coal from Oyon Region of Peru: Bureau of Mines Rept. of Investigations 4222, 1948, 9 pp.

72/ Fraser, Thomas, Coal in South America: Pan American Inst. Min. Eng. and Geol., Tech. Paper 6, 1948, 16 pp.

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A fundamental study of the forms of sulfur in the very low gravity fractions[73] of some important bituminous coals was made to ascertain if there were any significant differences in the inherent sulfur content of the different petrographic components of the coal that are separable by carefully controlled specific-gravity classifications. The specific-gravity fractions showed only very minor variations (fig. 24) in organic sulfur content, mostly within the range of experimental error. These variations are too small and irregular to have practical importance in preparing the coal. With respect to pyritic sulfur, which is the predominant form in most of our coking coals, there is a progressive improvement, with decrease in specific gravity continuing into the very light fractions as shown in figure 25. This indicates possibilities of substantially improving the grade of the coals if commercially applicable methods can be developed for controlled separation of the raw-coal mixtures at very low gravities.

Drying Low-Rank Coals

Flash-Drying Process

During 1946 and 1947, considerable interest was focused on the problem of drying low-rank coals for industrial use. Because of pending shortages of natural gas in the northeastern Wyoming and Montana area, several large users of gas in the Rocky Mountain region, particularly power and cement plants, were obliged to convert to subbituminous coal. Industrial interest in the improvement of subbituminous coal and lignite encouraged an accelerated study of the drying problem for both cement-burning and briquetting.

A study of drying plants operating on subbituminous coal showed that the rotary driers used at cement plants were inefficient and costly, although the cement kilns were operating satisfactorily on the processed coal. One drying plant reduced the moisture from 31 to about 20 percent in a single-stage rotary, while the other plant reduced moisture from 12 to 6 percent in a two-stage drier. It was indicated that rotary drying processes, normally used for removing surface moisture from coal, are fundamentally unsuited for the low-rank coals because the time of contact in the drier and the temperatures developed are not sufficient to remove the bed moisture.

Experiments in the laboratory revealed that bed moisture could be removed from fine coal in a few seconds by flash-drying with hot gases. Accordingly, this phase of drying low-rank coals was studied further, and investigations were made to determine if flash-dried subbituminous coals were suitable for briquetting. A pilot plant for handling about 2 tons of coal per day was built, as illustrated in figure 26. Several tests proved that subbituminous coal up to 1/16-inch size can be flash-dried in 1 to 2 seconds to remove 90 percent of the bed moisture at an indicated efficiency of about 90 percent. It was further proved that drying coal by this method was a straightforward thermal and materials-handling problem, and large plants could be designed from the data developed.

The experimental work on flash-drying 1/16-inch x 0 coal was done in cooperation with the Natural Resources Research Institute of the University of Wyoming, where a pilot plant for briquetting coal is in operation.

73/ Fraser, Thomas, and Crentz, W. L., Sulfur in Low-Gravity Fractions of Some Bituminous Coals: Bureau of Mines Rept. of Investigations 4167, 1947, 6 pp.

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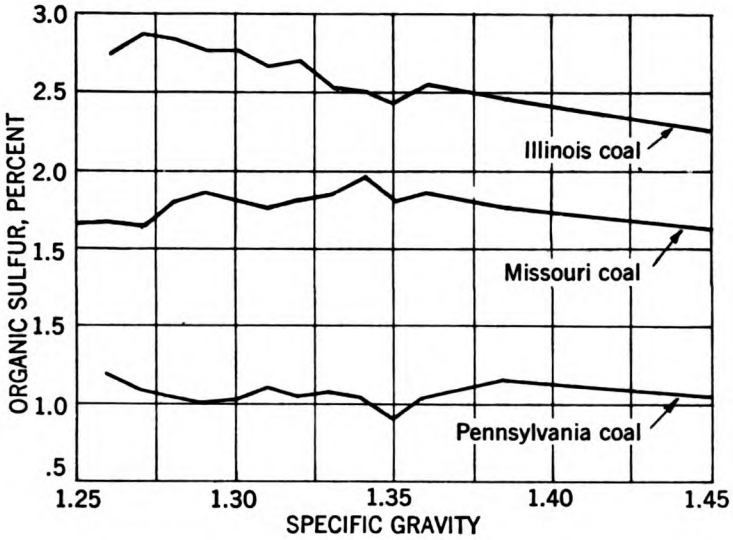

Figure 24. - Organic sulfur content of various specific-gravity fractions.

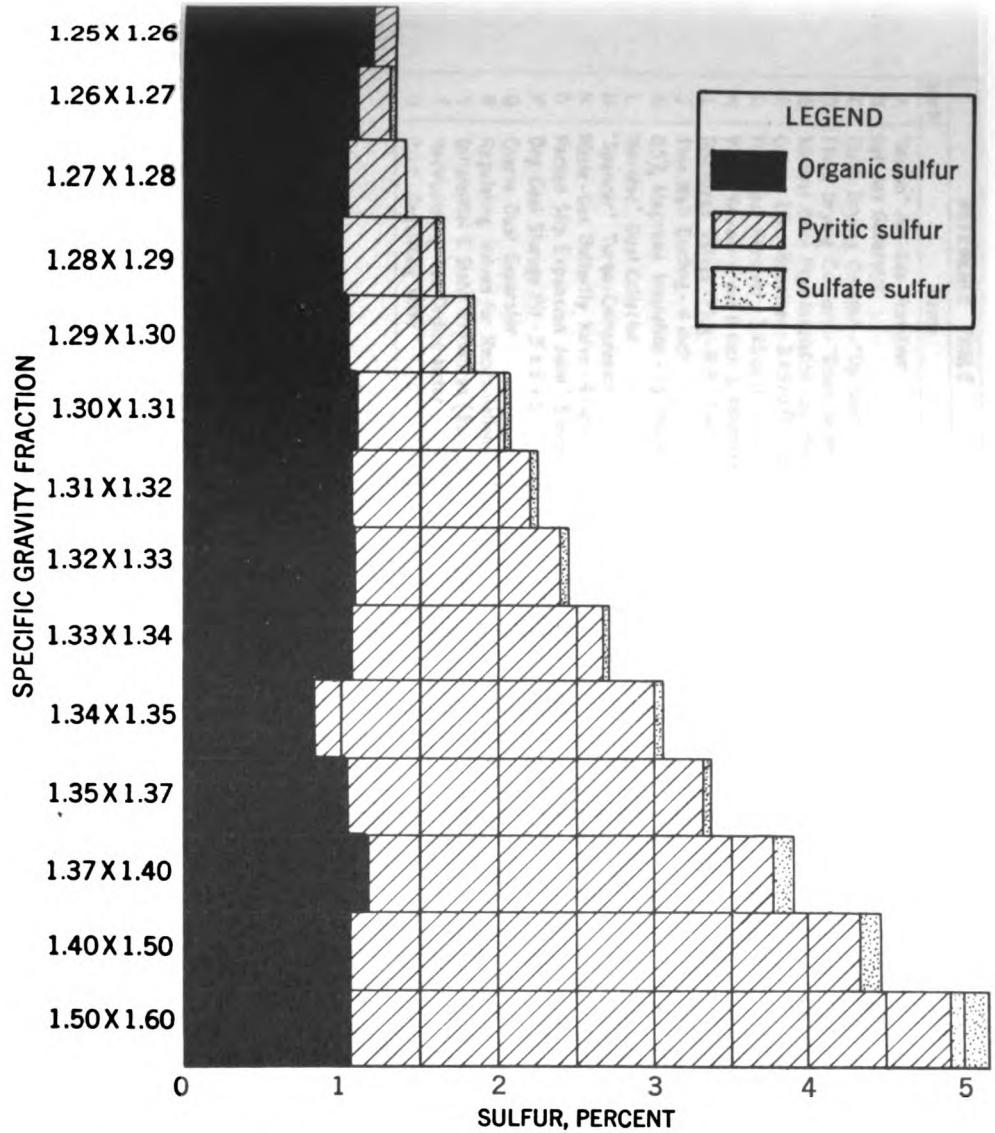

Figure 25. - Variations of forms of sulfur in specific gravity fractions of a Pennsylvania coal.

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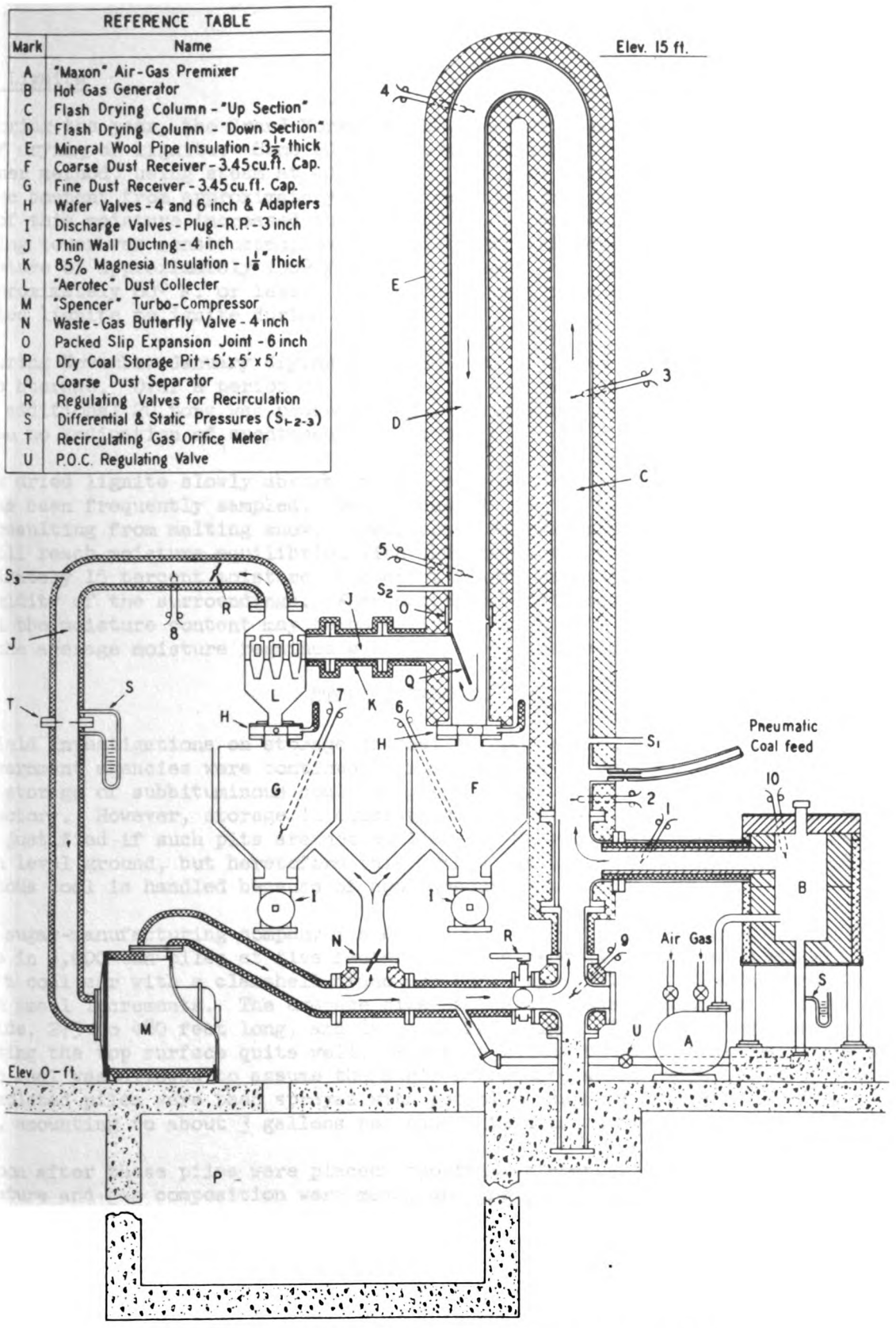
REFERENCE TABLE
Mark | Name
A "Maxon" Air-Gas Premixer
B Hot Gas Generator
C Flash Drying Column - "Up Section"
D Flash Drying Column - "Down Section"
E Mineral Wool Pipe Insulation - 3½" thick
F Coarse Dust Receiver - 3.45 cu.ft. Cap.
G Fine Dust Receiver - 3.45 cu.ft. Cap.
H Wafer Valves - 4 and 6 inch & Adapters
I Discharge Valves - Plug - R.P. - 3 inch
J Thin Wall Ducting - 4 inch
K 85% Magnesia Insulation - 1⅛" thick
L "Aerotec" Dust Collecter
M "Spencer" Turbo-Compressor
N Waste-Gas Butterfly Valve - 4 inch
O Packed Slip Expansion Joint - 6 inch
P Dry Coal Storage Pit - 5' x 5' x 5'
Q Coarse Dust Separator
R Regulating Valves for Recirculation
S Differential & Static Pressures (S_{1-2-3})
T Recirculating Gas Orifice Meter
U P.O.C. Regulating Valve
Elev. 15 ft.
Elev. 0 - ft.
Pneumatic Coal feed
Air
Gas

Figure 26. - Flash drier for fine coal, Golden, Colo.

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Drying Lignite

During the year, the Grand Forks, N. Dak., Pilot Plant continued its investigation of drying of lignite. Some 200,000 pounds of lignite was dried by the modified Fleissner method, using steam at 400 p.s.i. Although this operation reduced the moisture content from approximately 37 percent to approximately 12 percent, the removal of this moisture increased the tendency to spontaneous ignition. To this end, a cooling tower was constructed, over which the freshly dried coal was passed at a temperature of approximately 150° F. After passage over the tower, the temperature was approximately 80° F. or less. This drop in temperature reduced the tendency of the dried lignite to ignite during storage.

During November-January drying runs, 20 tons of dried lignite was placed in outside storage. Over a period of 7 months, no spontaneous ignition occurred. In May an additional 20 tons was placed in inside storage; to the end of June there had been no indication of spontaneous ignition.

As dried lignite slowly absorbs moisture from the air, the outside storage pile has been frequently sampled. During the winter, it was exposed to snow and the water resulting from melting snow. Preliminary experiments indicate that dried lignite will reach moisture equilibrium with the atmosphere when the lignite contains approximately 15 percent moisture, the exact figure depending upon the temperature and humidity of the surroundings. When extreme conditions, such as snow or rain, prevail the moisture content may temporarily exceed this value. From January through April the average moisture regained was one percent per month.

STORAGE OF COAL

Field investigations on storage of coal in cooperation with industrial concerns and Government agencies were continued during the year. Several years of practice in the storage of subbituminous coal in open pits has proved that this method is satisfactory. However, storage in concrete pits is expensive, and the method might not be justified if such pits are not available. Many concerns desire to store coal on level ground, but heretofore this method has not been feasible when subbituminous coal is handled because of spontaneous combustion.

A sugar-manufacturing company placed 25,000 tons of subbituminous A coal in storage in 5,000-ton piles at five factories. The general method employed was to unload a coal car with a clamshell crane and build up a pile by distributing the coal in small increments. The average size of the completed piles was 40 to 60 feet wide, 275 to 480 feet long, and 14 to 24 feet high. The piles were leveled, compacting the top surface quite well. The side walls, however, were not compacted and the coal was allowed to assume the angle of repose, which ranged from 35° to 40°. The completed piles were then sprayed with petroleum asphalt to form a surface veneer, amounting to about 3 gallons per square yard of surface.

Soon after these piles were placed, spontaneous combustion set in. Surveys of temperature and gas composition were made, and the physical condition of the several piles was determined. It was found that the sides were loosely packed and the asphalt veneer did not seal the sides. All of the piles were undergoing spontaneous combustion along the sides, and it appeared to be only a matter of time before the coal would have to be removed. Hot spots were corrected as far as possible, and attempts were made to allay combustion by covering the sides with 1 to 2 feet of cinders. None of these attempts were successful, and within 90 days all of the piles

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had to be moved to prevent further loss. This rather costly experiment by the company proved conclusively that ordinary storage of subbituminous coal on level ground is not feasible and that the asphalt capping was not beneficial.

The need for storing subbituminous coal increased during the fall of 1947 and the spring of 1948, and plans were formulated to build a model pile of 5,000 tons under the most favorable conditions. Figure 27 shows the placing of the model pile at the Brighton sugar plant. The pile was carefully designed to restrict air circulation, and the coal was placed in the following manner: (1) Coal was unloaded from cars with a clamshell crane and spotted over the storage area in small piles; (2) the small piles were then leveled and compacted with an Athey loader (as shown in figure 27), which made the benches about 6 inches thick; (3) the unloading crane then placed new coal on top of the first bench, and the pile was again leveled; and (4) precautions were taken to maintain the slope of all sides of the pile at about 17° and to compact all surfaces as the pile built up. The center height of the final pile was approximately 10 feet, and the base was approximately 118 by 290 feet. Measurements of the pile indicated that bulk densities of 65 to 70 pounds per cubic foot were attained by this method.

The model pile was placed during February-April 1948, and during 103 days of summer storage there was no evidence of spontaneous combustion. This proved method of safe storage for all low-rank coals requires careful supervision during placement of the coal and somewhat more area than is required for ordinary storage. A similar pile was completed at the Windsor sugar plant during June 1948, and the Bureau will continue the study of this pile.

Similar experiments were made on the storage of natural lignite at the Garrison Dam site in North Dakota in cooperation with Army Engineers, and a model pile of 9,000 tons was placed late in 1947 (see fig. 28). There has been no evidence of heating at this pile, and it is planned to extend the method to build up piles 40 feet high to take care of 1 million tons. Several such piles will be needed to accommodate the 5,000,000 tons of lignite to be removed from the dam site.

UTILIZATION OF COAL FOR COMBUSTION

Fuel-Engineering Service

Fuel-engineering service to Government establishments in the selection and use of fuel and fuel-burning equipment and in the economical use of steam was continued. Such services were utilized, particularly by installations in the Washington area as listed below:

(1) At Fort Leslie J. McNair, Washington, D. C., changes in stoker-control adjustments reduced the fuel bill $3,000 a year;

(2) Analyses of combustion products from oil-fired boilers at the Howard University power plant, Washington, D. C., during low-load periods resulted in adjustments saving $1,000 of fuel oil a year;

(3) As a result of tests at Gallinger Municipal Hospital boiler plant, Washington, D. C., recommendations for better oil-burner operation were made which will reduce operating costs $4,000 a year; a survey of steam-utilization practices at this hospital indicated that $13,000 could be saved yearly by closer control of steam for heating buildings;

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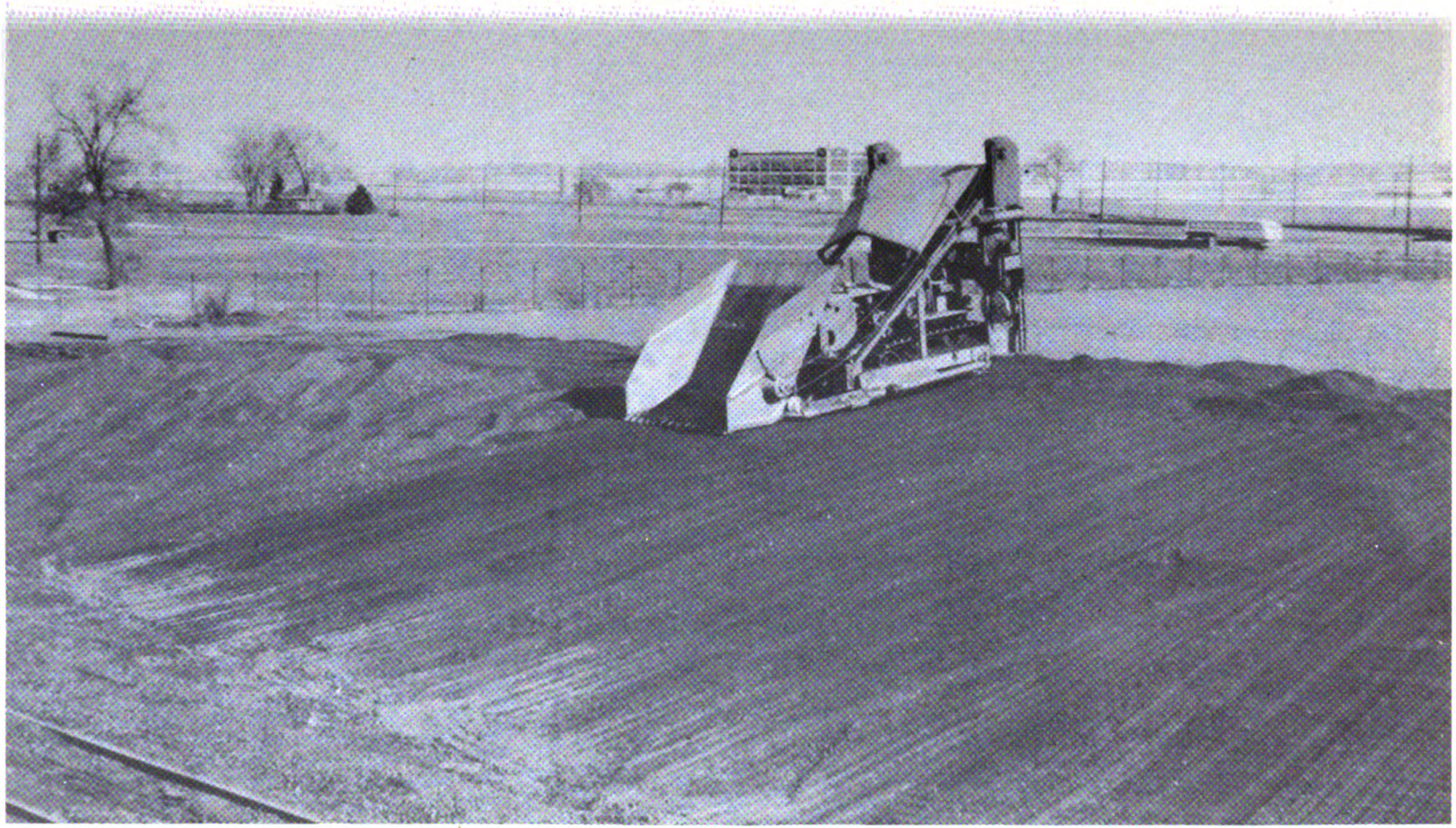

Figure 27. - Model subbituminous-coal storage pile. The pile is built in thin layers, and the sides are compacted at an angle of 17°.

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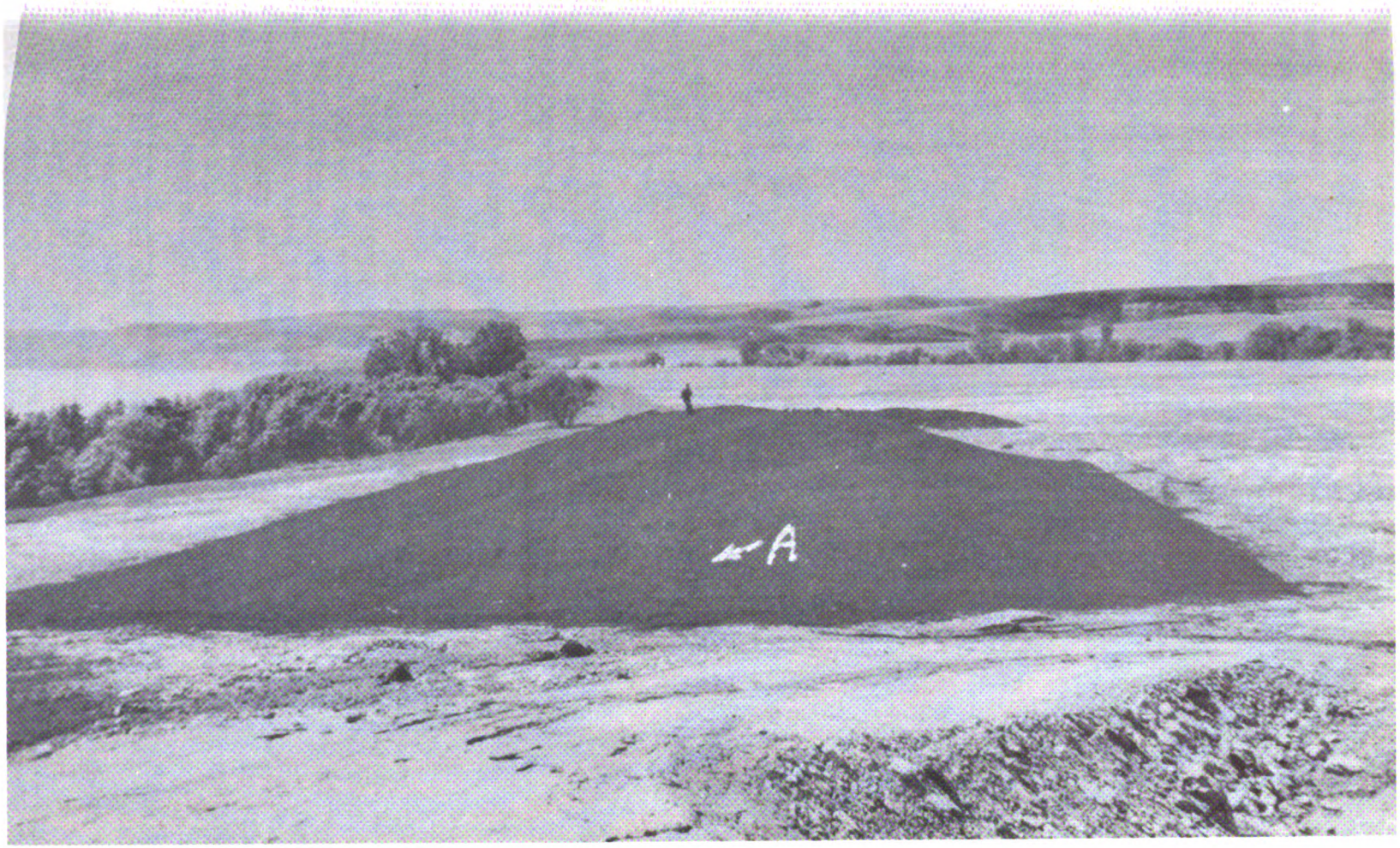

Figure 28. - Experimental storage of lignite, Garrison, N. Dak.

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(4) At the request of the Columbia Institution for the Deaf, Washington, D. C., recommendations were made for instruments and operating methods to reduce smoke emission from the stack of the central boiler plant;

(5) Recommendations were made pertaining to firing procedures and type and size of coal to be fired at six housing projects, comprising 1,469 dwelling units individually heated, supervised by the National Capital Housing Authority of Washington, D. C. It is estimated that the recommendations made will result in yearly savings of $11,500;

(6) A survey was made of boiler-plant operation and steam-utilization practices at Lincoln Heights Dwellings of the National Capital Housing Authority, Washington, D. C., which resulted in annual savings of $2,600.

Upon request, service was rendered to Government fuel-burning plants elsewhere in the United States and Alaska as follows:

(1) Studies of boiler-plant equipment and operation made at Fort Richardson and Ladd Field, Alaska, resulted in saving a proposed expenditure of $196,000 for new equipment;

(2) For the Veterans Administration, total operating-cost comparisons were made when using oil, gas, and coal, and the type of fuel-burning equipment recommended for 29 projects;

(3) Acceptance tests were made of a new boiler-and stoker-installation at the Fort Howard, Md., Veterans' Hospital, resulting in improved stoker equipment, saving $1,400 in fuel a year;

(4) Extensive testing was done in the boiler plant of the Veterans Administration Hospital at Lyons, N. J., to obtain needed data on the performance of chain-grate stokers burning anthracite Rice and Barley coal.

Coal-analysis limitations and purchasing procedures for all coal purchases of the Veterans Administration, the Office of Indian Affairs, and the Bureau of Reclamation were reviewed and changes recommended. Additional services on some 95 special problems were given 23 different Government agencies. A standard Federal specification for coke was promulgated. Experiences in the operation of Government plants were reported.74/ A handbook-type guide for reducing fuel consumption in commercial plants assembled in one volume educational "quiz sheets" and reference material used in the National Fuel Efficiency Program carried on during the war years.75/ Material was chosen that would have permanent value in detecting waste and in lowering fuel consumption. Each quiz sheet was prepared and checked by many engineers expert in the particular subject matter of the sheet. Committees of men with much experience in the manufacture and operation of equipment and in the training of operators helped in the work of preparation.

74/ Barkley, J. F., Experiences with Government-Operated Plants: Solid Fuel Eng., vol. 7, No. 2, November 1947, p. 8.
Barkley, J. F., Experiences with Government-Operated Plants: Coal-Heat, vol. 53, No. 2, February 1948, p. 29.

75/ Barkley, J. F., Cheasley, C. T., and Waddell, K. M., A Guide for Reducing Fuel Consumption in Commercial Plants: Bureau of Mines Bulletin 466, 1947, 168 pp.

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The Presidential edict of January 17, 1948, "Order for Conservation of Fuel Oil, Gasoline, and Gas," which carried a clause "No Federal equipment shall be installed for burning fuel oil or gas, or liquefied petroleum gas, and no permanent building or establishment shall be converted to these fuels, without the prior approval of the Bureau of Mines ----," required that over 300 projects be studied and approvals or disapprovals made.

The results of research at the Washington Naval Gun Factory on unusual corrosive deposits that accumulated on boiler tubes were published.76/ These deposits were very difficult to remove and caused much draft loss. Test data were obtained on two boilers, one equipped with an underfeed stoker with a long rear arch and water-cooled furnace, and the other equipped with an underfeed stoker without arch and a refractory furnace. Both used the same coal. Many factors were involved, such as the temperature of the collecting surface, the temperature of the gases, the quantity, size and chemical analysis of the fly ash, the relative amount of burning of SO_2 and SO_3, and the relative saturation of the moisture and of the sulfurous gases which depend upon the CO_2 carried and the amount of sulfur coming from the coal. Any one of these factors might be the governing one under a particular set of conditions. The deposit on specially devised ferrous test tubes characteristically had an inner layer of white deposit of ferrous sulfate, formed largely from the iron of the tube and sulfuric acid; the remainder of the deposit consisted chiefly of sulfates and silica, such as would be formed from entrained fly ash acted upon by sulfuric acid. The deposit can form on nonferrous equipment, showing that the initial action of sulfurous gases on iron is not necessary. The fact that the deposit can form at temperatures so much higher than are ordinarily anticipated from dew-point considerations calls for more study. It was found that larger quantities of fly ash physically sweep the tubes, apparently taking out a greater amount of sulfurous gases from the products of combustion. It appears reasonable to assume that the fly ash takes out SO_3 in preference to SO_2, probably resulting in an appreciably lower dew point of the gases. As an operating matter, it was found that, by dropping the CO_2 at the economizer inlet from above 14 percent for one boiler to about 12 percent CO_2, a year's operation could be had without draft loss and with only a small accumulation of deposit, which was effectively removed by an off-the-line water-washing procedure devised by the plant personnel. To obtain all of the test data needed it was necessary to analyze products of combustion for SO_2 and SO_3 content. It was found that the standard test method of the American Society of Mechanical Engineers, the only standard published, was unsatisfactory, since certain minerals from the coal destroyed the accuracy of the analytical test methods used. Changes and modifications of the standard were developed that resulted in a satisfactory method of analysis.

Cooperative research with the Air Preheater Corp. of New York on the prevention of deposits and corrosion of boiler-air preheaters was continued. Laboratory tests were run and field studies made of many installations throughout the United States. A great number of different metallic and nonmetallic elements are now under test.

76/ Barkley, J. F., Burdick, L. R., and Berk, A. A., Test Data on Gas-Side Sulfate-Type Deposits on Tubes Beyond the Boiler Furnace: Trans. Am. Soc. Mech. Eng., vol. 70, No. 2, 1948, pp. 81-89.
Barkley, J. F., Burdick, L. R., and Berk, A. A., Sulfate-Type Deposits on Boiler Tubes: Combustion, vol. 19, No. 1, July 1947, pp. 26-27.
Barkley, J. F., Burdick, L. R., and Berk, A. A., Gas-Side Sulfate-Type Deposits: Modern Power and Eng., vol. 41, No. 9, September 1947, pp. 68, 70, 72.

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Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made on 8,180 samples of boiler water during the fiscal year as follows: 5,388 from the Army and Air Forces, 1,432 from the Veterans Administration, 393 from the Housing Authority, 292 from the District of Columbia, 218 from the Office of Indian Affairs, 154 from the Justice Department, 131 from the Post Office Department, 60 from the Navy Department, 54 from the Public Health Service, 13 from the Commerce Department, 13 from the Agriculture Department, 11 from the Atomic Energy Commission, 9 from the Federal Security Agency, 7 from the War Assets Administration, 2 from the Public Buildings Administration, 2 from the Smithsonian Institution, and 1 from the Fish and Wildlife Service, Interior Department. Reports and recommendations covering 19 analyses of various scales, sludges, and deposits and 9 covering analyses of boiler compounds were made. An average annual saving of about $300.00 was effected by using standard chemicals instead of proprietary compounds at several Public Housing Administration projects. Two hundred and thirty-two special Bureau of Mines field water-test kits, 8,829 bottles of chemical reagents, and 10,677 test-kit replacement items were distributed to various Government activities.

Visits were made to 28 heating plants operated by a number of Federal agencies in the local area of the District of Columbia to determine difficulties, advise on boiler-water treatment, give instructions in boiler-water testing, and inspect boilers for scale and sludge. Upon request, service visits were made to installations outside this area as follows:

(1) A survey was made of the six-boiler plant of the Veterans Administration Hospital, Perry Point, Md., to determine the cause of repeated tube failures. Boilers were being retubed at a cost of $10,000 each. It was found that plugs of sludge forming in the tubes were stopping circulation, causing them to burn out. Recommendations for control were made to prevent this condition.

(2) A study of boiler-water treatment practices was made at the Veterans Administration Hospital, Aspinwall, Pa. The principal difficulty reported was return-line corrosion. This was caused by sluggish circulation, as water filled the lines and essentially stood for long periods; the oxygen concentration in the return water decreased as it moved along in the line. It was recommended that changes in the system be made to increase the rate of flow of the condensate. At this plant, it had been found necessary to replace a set of five 150-hp. horizontal-return tubular boilers about every 10 years at a cost of $50,000. The present set of boilers is being treated chemically in accordance with Bureau of Mines procedure, and the condition of the boilers is being kept satisfactory.

At the Jefferson Junior High School, Washington, D. C., the boiler water of a three-boiler plant was treated under supervision of the Bureau of Mines, and no tube failures occurred. Without this treatment, such boilers had been costing $1,400 each for tube replacement every few years. A detailed analysis of savings resulting from Bureau of Mines procedures of boiler-water treatment made at the Atomic Energy Commission, Los Alamos, N. Mex., showed that $139,000 were saved annually in operating 40 boilers.

At the request of the Post Office Department, a special questionnaire on boiler-water treatment was prepared for its use in making surveys of the Post Office low-pressure boiler plants. A Navy Department manual on boiler-water treatment was reviewed, and suggestions were made for revision, and a questionnaire on boiler-water

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treatment for use in making a survey of Navy plants was prepared in collaboration with Navy Department chemical engineers. Consulting service was given the Public Buildings Administration on corrosion control in low-pressure boilers; the District Government, on the use of sodium sulfite to protect idle boilers; the Veterans Administration, on the protection of idle boilers from corrosion, the use of external phosphate softening, the preparation of log sheets for recording boiler water treatment data at all plants, external water treatment for a proposed hospital at Marlin, Tex., and a special water-treating device at Boise, Idaho; the Post Office Department, on tube cleaners for water-tube boilers, on threshold treatment, the preparation of instructions for the feeding of boiler-water chemicals, and boiler-tube difficulties at Boston, Mass.; the Bureau of Yards and Docks, on a special water-treatment condition at Tacoma, Wash.; the Fish and Wildlife Service, Interior Department, on the use of boiler compounds; and the Army on new schemes of water analysis.

Boiler-Water Research

Research was continued during the fiscal year on the use of volatile alkaline amines in boiler water. These chemicals volatilize and condense with the steam, neutralizing any carbonic acid content of the steam and also removing accumulations of solid corrosion products in the piping. Studies are being made to reduce treatment cost for greater savings and therefore possible extension to plants in which the corrosion problem is not of major importance. The degree of volatility and alkalinity most desirable varied with operating conditions of the plant. Volatility was especially important at low pressures. A highly volatile compound, such as cyclohexylamine, was more suitable for systems operated at 5 to 15 pounds pressure, while at higher pressures, and especially for systems operated at about 100 pounds per square inch, a less-volatile amine can be used, such as morpholine. Morpholine, with its relatively low alkalinity, permits a greater elimination of carbon dioxide at the vents in the heating system.77/ Corrosion tests in the field and in the laboratory verified the general operating experience that chemical treatment of steam systems with amines effectively reduces the corrosiveness of the condensate when it is maintained slightly on the alkaline side. At one Federal Public Housing project where experimental work was being done, it was found that about $500.00 per year could be saved by substituting a more-appropriate amine than was formerly being used. Laboratory testing data were obtained on the effects of rate of flow, carbon dioxide concentration, dissolved oxygen concentration, and temperature on the rate of corrosion of pipe sections. A study of the effect of ammonia in condensate on the deterioration of brass and other copper alloys was begun.

Research work on caustic embrittlement or intercrystalline cracking in locomotive boilers - a very serious problem of the railroads - is being rounded out through field test work. Sodium nitrate treatment has proved to be the most satisfactory method for controlling cracking, protecting the metal by forming and keeping in repair a continuous film on the steel of the boiler seams. Embrittlement detectors were maintained on 16 locomotive boilers to determine whether the treatment was satisfactory. The evidence of the detectors, plus a very large decrease in the number and severity of the cracks found, showed the treatment to be effective.

77/ Berk, A. A., Treating Steam Chemically to Reduce Return-Line Corrosion: Ind. and Power, vol. 53, No. 5, November 1947, pp. 79-81, 110, 112.

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Smoke Abatement

Civic interest in smoke abatement continued high through the year, with many requests coming to the Bureau of Mines from various cities for publications and consulting service, including Los Angeles, Calif.; Denver, Colo.; Coffeeville, Kans.; Mount Sterling, Ky.; Portland, Maine; Muskegon, Mich.; Kansas City and St. Louis, Mo.; Albany, Elmira, Kenmore, and New York, N. Y.; Portsmouth, Ohio; Erie and Philadelphia, Pa.; Memphis, Tenn.; Houston, Tex.; Provo, Utah; Richmond, Va.; Parkersburg, W. Va.; Manitowoc, Milwaukee, and Reedsburg, Wis.; and Kingston, Ontario, Canada. Information and consulting service were also given Allegheny County, Pa. Smoke abatement as related to anthracite was discussed in a published report.78/

Coal and Energy in the Western States

A study of the western fuel situation showed that, with the increasing demand for energy coincident with increase in population, the production of coal in the Western States probably will increase threefold in 25 years if there is no substantial increase in oil production.79, 80/

A résumé of Bureau of Mines research and development work on western coals during 1942-47[81]/ discussed drilling projects to locate and evaluate new sources of coking coal, carbonizing properties of coal, storage of coal, drying of low-rank fuels, combustion of low-rank coals, gasification of subbituminous coal and lignite, and investigations in progress at Golden, Colo., and at Grand Forks, N. Dak., in 1947.

Removal of Ash as Molten Slag from Pulverized-Coal-Fired Furnaces

In 1947 there was burned in the boilers in the electric power stations of the United States a record quantity of 86,000,000 tons of coal, most of it in pulverized form. Probably the most important single variable affecting the efficient and continuous operation of these utility boilers is the nature and behavior in the furnace of the ash in the coal. Because the quality of coal economically suitable for utility consumption has steadily declined, many units now on order are designed for coals containing 12 to 15 percent ash, making it increasingly difficult to meet the continued upward trend in final steam temperatures, reaching 1,000° F. in units recently installed.

To provide the basic information required for an understanding of the behavior of ash, the Bureau of Mines has for many years conducted a systematic study of the properties of ash and slag and the behavior of ash in furnaces. To clarify the current status of the knowledge of coal ash, as it is related to behavior in pulverized-coal furnaces, a publication[82]/ summarized what is known of (a) the fundamental flow

78/ Barkley, J. F., Anthracite's Part in Smoke Abatement: Trans. 6th Ann. Anthracite Conf. of Lehigh University, May 1948, pp. 35-42.

79/ Parry, V. F., Trends in the Production of Coal and Energy in the Western States as a Result of the War: Proc. Rocky Mt. Coal Min. Inst., 1947, pp. 10-18.

80/ Parry, V. F., Future Prospects for Western Fuel Supply: Western Industry, 1948, Rocky Mt. Petrol. Year Book, 1947-48: spec. issue, Oil Reporter, spring 1948, pp. 33-36.

81/ Parry, V. F., Résumé of Bureau of Mines Research and Development Work on Western Coals, 1942-47: Bureau of Mines Rept. of Investigations 4171, 1948, 9 pp.; Proc. Rocky Mt. Coal Min. Inst., 1947, pp. 18-26.

82/ Cohen, P., and Corey, R. C., Behavior of Ash in Pulverized-Coal-Fired Furnaces: Combustion, vol. 19, No. 1, January 1948, pp. 33-40.

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properties of coal-ash slag, (b) the behavior of ash and slag deposits on heat-absorbing surfaces, and (c) means for applying the data available on ash and slag to practical problems of interest to operators and designers.

Measurement of Heat Absorption in the Primary Furnace of a Central Station Boiler

The absorption of heat in the furnace of a large boiler is determined by many factors as yet imperfectly understood. To provide a basis for the rational and economical design of boilers, and to permit the most economic use of available coals, the Special Research Committee on Furnace Performance Factors of the American Society of Mechanical Engineers has initiated a program of investigation of representative boilers, to determine the effect of surface to volume ratio, method of firing, load, excess air, and cleanliness of furnace walls, on heat absorption in boiler furnaces.

The Bureau of Mines, cooperating with this committee in this investigation, has applied improved methods of measuring temperature and composition of furnace gases, to the determination of heat absorption in boiler furnaces. The study of one unit has been completed[83] and work is in progress on a second unit.

CARBONIZATION AND GASIFICATION

Small-Scale Laboratory Carbonization Tests

As part of the survey of the gas- and coke-making properties of American coals, small-scale laboratory carbonization tests are made of various coals to evaluate their metallurgical coke-making properties. These tests include the United States Steel Corp. high-temperature distillation test, Fischer low-temperature carbonization assay, and the Bureau of Mines agglutinating-value test. During the year three high volatile A bituminous coals from the following sources were examined by these methods: Lower Banner bed, No. 56 mine, Dante, Russell County, Va.; Chilton bed, Lorado No. 5 mine, Larado County, W. Va.; and Lower Cedar Grove and Alma A beds, Omar No. 5 mine, Omar, Logan County, W. Va. Generally the yields of carbonization products were similar for the coals.

The results of small-scale carbonization tests[84] of washed coal from the Hill bed, Cherokee County, Ala., showed that this coal yields less gas and more tar in the Fischer assay than in the BM-AGA tests at 500° and 600° C. because the volatile products escape from the Fischer retort with less cracking. The yield of coke in the assay is intermediate between BM-AGA yields at 500° and 600° C. The yields from the United States Steel Corp. high-temperature distillation test approximate those from the BM-AGA test at 900° C.

Agglutinating-value tests were made of 103 drill-core samples of coal submitted in connection with investigations to determine minable reserves of coking coals in the Castleman Basin field in western Maryland and the Coal Creek district in Gunnison

83/ Reid, W. T., Cohen, P., and Corey, R. C., An Investigation of the Variation in Heat Absorption in a Pulverized-Coal-Fired, Water-Cooled Steam-Boiler Furnace. Part II. Furnace Heat Absorption Efficiency, as Shown by the Temperature, Composition, and Flow of Gases Leaving the Furnace: Trans. A.S.M.E., vol. 70, No. 5, July 1948, pp. 569-585.

84/ Davis, J. D., Reynolds, D. A., Ode, W. H., Brewer, R. E., Wolfson, D. E., and Birge, G. W., Carbonizing Properties of Hill-Bed Coal from Hickey No. 1 Mine on Lookout Mountain, Cherokee County, Ala.: Bureau of Mines Tech. Paper 703, 1947, 40 pp.

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County, Colo. Agglutinating values of the Castleman Basin coals ranged from 3.3 to 11.7 kilograms; these values show that most of these coals are medium to strongly coking. The Coal Creek coals of Colorado has agglutinating values ranging from 3.8 to 6.5 kilograms, which indicates that the coals examined having coking properties generally superior to those of the Lower Sunnyside coals of Utah, a standard western coal for making metallurgical coke.

Low-temperature tar yields by the Fischer laboratory assay were determined on five face samples of high-volatile C bituminous coal from Sweetwater County, Wyo., in connection with preparation of process estimates by the Bureau of Mines Synthetic Oil Plant for large-scale hydrogenation studies. The yields of tar ranged from 25 to 28 gallons per ton of coal, which are considered normal for coals of their rank.

The yields of low-temperature carbonization products were determined by the Fischer assay on a sample of wash 3- by 1/2-inch nut coal from the Corona bed, Corona No. 20 mine, Walker County, Ala., as a part of a study of complete gasification of this coal. The yields of low-temperature carbonization products on an as-received coal basis were as follows: Coke, 72.1 percent; tar, 35 gallons per ton; light oil, 2.5 gallons per ton; and gas, 1,940 cubic feet per ton.

Fischer low-temperature carbonization assays were made of 18 samples of Upper Cretaceous coals from northern Alaska to determine their value as a potential source of liquid fuel. The samples were collected in the summer of 1947 by the Federal Geological Survey in connection with the Navy Department's petroleum investigations in Naval Petroleum Reserve No. 4. The range of yields of carbonization products on an air-dried coal basis was as follows: Carbonized residue, 63 to 86 percent; tar, 5.8 to 33.8 gallons per ton; light oil, 0.50 to 2.30 gallons per ton; and gas, 1,210 to 3,570 cubic feet per ton. One coal formed a nonswollen coke that was very weak and friable. The carbonized residues from seven coals showed evidence of very slight fusion. The other 11 samples were noncoking in the Fischer assay, the carbonized residues being loose powders.

Survey of Carbonizing Properties of American Coals

Two coals were tested during the year for complete BM-AGA yields and quality of products obtained at low, medium, and high temperatures. Both were West Virginia high-volatile A coals - No. 93 represented the Chilton bed, Lorado No. 5 mine, Lorado, Logan County, W. Va.; and No. 94 represented the Lower Cedar Grove-Alma A beds, Omar No. 5 mine, Omar, Logan County, W. Va. Two other coals - No. 322 representing the Upper Elkhorm bed, prospect hole No. 1, Knott County, Ky., and No. 328 the Palau No. 5 mine, State of Coahuila, Mexico - were tested by the BM-AGA method at high temperature. The source and analyses of the coals carbonized are given in tables 7 and 8. The yields and quality of the products from the BM-AGA tests are given in tables 9 to 13, inclusive. Expansion and plasticity data obtained on these coals are described in other sections of this report.

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TABLE 7. - Description of coals and blends tested

Coal No.	Description
93	Chilton bed, Lorado No. 5 mine, Logan County, W. Va.
a93-b93	Expansion samples from various parts of Lorado No. 5 mine.
c93	Expansion sample from prospect hole, Chilton bed.
93A	80 percent Chilton (93) and 20 percent Pocahontas No. 3 (75).
93B	70 percent Chilton (93) and 30 percent Pocahontas No. 3 (75).
94	Lower Cedar Grove-Alma A beds, Omar No. 5 mine, Logan County, W. Va.
a94	Expansion sample, Lower Cedar Grove bed.
b94	Expansion sample, Alma A bed.
c94-d94-e94	Expansion samples from various parts of Omar No. 5 mine.
94A	80 percent Lower Cedar Grove-Alma A (94) and 20 percent Pocahontas No. 3 (75).
94B	70 percent Lower Cedar Grove-Alma A (94) and 30 percent Pocahontas No. 3 (75).
b316	Corona bed, Corona mine, Walker County, Ala.
b316A	80 percent Corona (b316) and 20 percent Pocahontas No. 3 (75).
317	Pocahontas No. 3 bed.
317A	20 percent Pocahontas No. 3 (317) and 80 percent Pittsburgh (28).
322	Upper Elkhorn No. 3 bed, prospect opening No. 1, Knott County, Ky.
a322	Resample of Upper Elkhorn No. 3 (322), cleaned at 1.50 specific gravity, and tested in 60-mesh size.
322A	80 percent Upper Elkhorn No. 3 (322) and 20 percent Pocahontas No. 3 (75).
322B	70 percent Upper Elkhorn No. 3 (322) and 30 percent Pocahontas No. 3 (75).
322C	50 percent Upper Elkhorn No. 3 (322), 30 percent Pittsburgh (28), and 20 percent Pocahontas No. 3 (75).
323	Lower Freeport bed, Kramer mine, Jefferson County, Pa.
323A	40 percent Lower Freeport (323), 30 percent Pittsburgh (324), and 30 percent Pittsburgh (325).
324	Pittsburgh bed, Banning No. 1 mine, Fayette County, Pa.
325	Pittsburgh bed, Hutchinson mine, Westmoreland County, Pa.
326	Lower and Upper Freeport beds, Kent Nos. 1 and 2 mines, Indiana County, Pa.
a326	Resample of Lower and Upper Freeport beds (326) from new areas.
326-S-2	Resample of Lower and Upper Freeport beds (326) after storage for 6 months.
326-S-3	Resample of Lower and Upper Freeport beds (326) after storage for 6 months, crushed through hammer mill.
327	Thick Freeport bed, Renton No. 3 mine, Allegheny County, Pa.
b328	Carbonifera Unida Palau, Palau No. 5 mine, Palau, Coahuila, Mexico. Cleaned by heavy-media process. Expansion sample 2- by 1/4-inch.
328A	Carbonifera Unida Palau, Palau No. 5 mine, Palau, Coahuila, Mexico. 45.9 percent of 2- by 1/4-inch and 54.1 percent of 1/4- by 0-inch.
331	Upper Freeport bed, Watson mine, Indiana County, Pa.
332	Sewell (or Davey) bed, Twin Branch mine.
333	Pocahontas No. 6 bed, Black Eagle mine.
334	Pittsburgh bed, Vesta mine, Washington County, Pa.
335	Upper Freeport bed, Ernest mine, Indiana County, Pa.
335-S-2	Upper Freeport (335) crushed to finer size in hammer mill.
336	Blend used in by-product ovens at Pittsburgh, Pa.
338	Lower Thacker bed.

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TABLE 7. - Description of coals and blends tested (con.)

Coal No.	Description
341	Pocahontas bed coal blended at by-product plant, Indiana Harbor, Ind.
342	Upper Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky., slack coal.
342A	65 percent Upper Elkhorn No. 3 (342) and 35 percent Pocahontas (341).
342B	40 percent Upper Elkhorn No. 3 (342), 35 percent Pocahontas (341), and 25 percent Upper Elkhorn No. 3 (343).
343	Upper Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky., egg coal.
344	Corban: Mixture of various high-volatile Kentucky and West Virginia coals carbonized commercially at Indiana Harbor, Ind.
344A	65 percent Corban (344) and 35 percent Pocahontas (341).
344B	50 percent Corban (344), 35 percent Pocahontas (341), and 15 percent Upper Elkhorn No. 3 (343).
75	Pocahontas No. 3 bed, Kimball, McDowell County, W. Va. (Low-volatile blending coal.)
28	Pittsburgh bed, Warden mine, Allegheny County, Pa. (High-volatile blending coal.)

TABLE 8. - Analyses of coals, as-received basis[1/]

Coal No.	Dry, mineral-matter-free, fixed carbon, percent	Proximate, percent				Ultimate, percent					Air drying loss, percent	Heating value, B.t.u. per pound	Softening temperature of ash, °F.
		Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur			
93	62.6	1.8	35.2	57.9	5.1	5.3	80.6	1.4	6.9	0.7	0.6	14,330	2,630
a93	63.9	1.9	33.9	58.9	5.3	5.2	80.8	1.4	6.5	.8	.9	14,300	2,650
b93	63.9	1.8	33.7	58.3	6.2	5.2	80.0	1.4	6.4	.8	.7	14,190	2,660
c93	63.7	1.8	33.8	58.1	6.3	5.3	79.8	1.5	6.4	.7	.8	14,190	2,840
93A	67.8	1.9	30.2	62.3	5.6	5.2	81.1	1.4	6.0	.7	.9	14,360	2,540
93B	69.5	1.9	28.6	63.8	5.7	5.0	80.9	1.3	6.4	.7	1.0	14,320	2,550
94	62.0	3.0	34.7	55.3	7.0	5.2	77.3	1.4	8.5	.6	1.5	13,690	2,680
a94	61.4	2.2	36.4	57.0	4.4	5.4	79.6	1.8	8.1	.7	.8	14,170	2,620
b94	60.7	1.9	37.1	56.5	4.5	5.4	79.8	1.8	7.8	.7	.7	14,210	2,470
c94	61.5	2.3	36.0	56.6	5.1	5.4	79.2	1.5	8.1	.7	1.1	14,010	2,430
d94	61.3	2.2	36.1	56.2	5.5	5.4	78.9	1.5	8.1	.6	.9	14,010	2,520
e94	61.6	1.9	36.4	57.7	4.0	5.4	80.5	1.5	7.9	.7	.7	14,230	2,540
94A	66.1	2.8	31.1	59.2	6.9	5.1	78.1	1.4	7.9	.6	1.4	13,720	2,520
94B	69.0	2.7	28.5	61.6	7.2	5.0	78.3	1.3	7.5	.7	1.5	13,780	2,450
b316	56.1	3.1	38.7	47.9	10.3	5.4	70.7	1.6	9.4	2.6	1.6	12,850	2,280
b316A	62.6	2.5	33.7	54.3	9.5	5.1	73.7	1.6	7.7	2.4	1.3	13,260	2,250
317	80.3	4.1	18.1	70.8	7.0	4.5	80.0	1.2	6.5	.8	3.3	13,890	2,440
317A	65.6	1.9	32.1	60.0	6.0	5.2	78.8	1.3	7.9	.8	.8	14,060	2,620
322	59.2	4.7	37.5	53.6	4.2	5.6	75.8	1.5	12.0	.9	1.5	13,530	2,220
322A	63.0	3.9	34.2	57.2	4.7	5.4	77.2	1.4	10.4	.9	1.2	13,650	2,280
322B	65.8	3.7	31.7	59.8	4.8	5.3	77.2	1.4	10.4	.9	1.4	13,740	2,310
322C	64.3	3.1	33.2	58.7	5.0	5.3	78.0	1.5	9.3	.9	.9	13,830	2,470
323	68.4	2.9	28.8	60.5	7.8	5.1	77.2	1.3	7.4	1.2	1.8	13,670	2,670
323A	64.9	3.4	31.7	56.8	8.1	5.2	76.1	1.4	8.1	1.1	2.1	13,550	2,620

See footnote at end of table on following page.

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TABLE 8. - Analyses of coals, as-received basis[1] (con.)

Coal No.	Dry, mineral-matter-free, fixed carbon, percent	Proximate, percent				Ultimate, percent					Air drying loss, percent	Heating value, B.t.u. per pound	Softening temperature of ash, °F.
		Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur			
324	62.3	3.6	34.0	54.7	7.7	5.4	75.6	1.6	8.6	1.1	2.5	13,490	2,680
325	61.9	3.1	34.0	53.6	9.3	5.2	74.0	1.4	8.9	1.2	1.8	13,320	2,610
326	67.7	3.6	29.0	58.7	8.7	5.2	76.4	1.3	7.2	1.2	2.6	13,550	2,600
a326	67.7	2.7	29.6	60.2	7.5	5.2	78.2	1.4	6.5	1.2	1.9	13,880	2,570
326-S-2	68.7	3.0	28.4	60.2	8.4	5.1	76.6	1.3	7.4	1.2	2.2	13,650	-
326-S-3	69.2	3.1	28.0	60.7	8.2	5.1	76.7	1.4	7.4	1.2	2.3	13,680	2,570
327	60.2	2.9	35.6	52.2	9.3	5.2	74.8	1.4	7.5	1.8	1.6	13,370	2,310
b328	75.7	1.6	21.5	62.1	14.8	4.6	73.3	1.2	5.2	.9	1.0	12,960	-
328A	75.2	1.8	22.1	62.9	13.2	4.7	75.0	1.3	4.9	.9	1.1	13,200	2,910
331	67.4	2.0	29.7	59.4	8.9	5.1	77.1	1.5	6.1	1.3	1.1	13,730	2,470
332	78.8	.6	20.6	74.8	4.0	4.7	85.9	1.5	3.1	.8	.2	14,980	2,570
333	81.5	1.4	17.5	73.5	7.6	4.4	82.0	1.3	4.0	.7	.9	14,220	2,870
334	61.6	.8	35.4	55.3	8.5	5.1	76.5	1.5	7.0	1.4	-	13,720	2,490
335	69.1	2.2	28.3	60.8	8.7	5.0	77.2	1.4	5.4	2.3	1.6	13,760	2,220
335-S-2	68.8	2.4	28.4	60.1	9.1	5.0	76.4	1.4	5.5	2.6	2.0	13,660	-
336	64.3	4.7	32.0	56.0	7.3	5.3	75.1	1.5	9.5	1.3	3.6	13,440	2,600
338	64.0	2.4	34.4	60.6	2.6	5.4	81.4	1.5	8.4	.7	.7	14,520	-
341	81.5	1.7	17.4	73.1	7.8	4.4	81.8	1.2	4.0	.8	.9	14,160	2,550
342	62.1	3.0	34.4	54.9	7.7	5.3	75.0	1.4	9.7	.9	.5	13,350	2,340
342A	68.1	2.5	29.3	60.8	7.4	5.0	77.6	1.4	7.8	.8	.8	13,690	2,470
342B	68.9	2.5	28.9	62.5	6.1	5.1	78.8	1.4	7.8	.8	.8	13,880	2,390
343	60.7	2.6	37.2	56.9	3.3	5.6	79.7	1.6	9.0	.8	.5	14,180	2,210
344	62.8	2.7	33.5	54.8	9.0	5.2	74.4	1.3	9.1	1.0	.7	13,280	2,570
344A	69.2	3.5	27.8	60.3	8.4	5.0	76.2	1.3	8.2	.9	1.5	13,340	2,550
344B	68.6	3.5	28.5	60.6	7.4	5.1	77.0	1.3	8.4	.8	1.8	13,550	2,550
75	82.2	3.2	16.6	72.7	7.5	4.4	80.8	1.1	5.5	.7	2.7	13,990	2,400
28	61.7	1.6	36.0	56.9	5.5	5.4	79.1	1.5	7.7	.8	.5	14,130	2,830

1/ Analyses made under supervision of H. M. Cooper, chemist, Bureau of Mines, Pittsburgh, Pa.

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TABLE 9. - Yields of carbonization products in BM-AGA tests, as-carbonized basis

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	Yields, percent by weight of coal[1]							Yields per ton of coal[1]				
			Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Gas, cubic feet	Tar, gallons	Light oil, gallons: In gas	Light oil, gallons: Tar to 170° C.	$(NH_4)_2SO_4$, pounds
93	13	600	74.2	9.0	10.3	0.71	0.078	4.7	99.0	4,400	23.7	2.22	1.47	6.1
93	13	700	71.8	12.5	8.6	.94	.218	5.8	99.9	7,100	18.6	2.74	1.03	24.0
93	13	800	70.5	14.2	7.6	1.02	.213	4.8	98.3	9,200	15.6	2.86	.61	23.6
93	18	900	70.9	15.1	6.4	1.18	.192	4.8	98.6	10,600	13.0	3.24	.44	20.2
93A	18	900	73.5	14.0	5.3	1.03	.192	4.9	98.9	10,400	10.9	2.81	.39	20.8
93B	18	900	74.5	13.4	5.1	.93	.181	4.8	98.9	10,200	10.5	2.57	.40	20.1
93	18	1,000	71.8	15.4	5.8	1.20	.172	4.5	98.9	11,600	11.5	3.29	.29	17.4
94	13	600	72.6	9.0	9.9	.50	.077	7.2	99.3	4,150	22.7	[3]/1.46	1.50	13.0
94	13	700	70.3	12.2	8.5	.91	.163	7.3	99.4	6,700	18.6	2.73	1.06	22.2
94	13	800	69.0	13.7	7.8	1.02	.175	6.7	98.4	8,600	16.5	2.93	1.11	23.3
94	18	900	69.4	15.5	6.0	1.16	.151	6.6	98.8	10,450	12.3	3.18	.66	21.4
94A	18	900	72.0	13.9	5.3	.95	.142	6.7	99.0	9,950	11.3	2.64	.62	21.3
94B	18	900	73.7	13.4	5.1	.92	.146	6.2	99.5	9,950	10.7	2.57	.59	20.4
94	18	1,000	69.2	15.8	5.5	1.16	.131	6.2	98.0	11,300	11.0	3.18	.36	17.0
322	18	900	64.8	17.4	6.3	1.26	.172	9.0	98.9	10,850	12.9	3.48	.55	23.5
322A	18	900	68.5	15.3	5.0	1.15	.173	8.4	98.5	10,600	10.4	3.17	.40	24.7
322B	18	900	70.6	15.0	4.3	.89	.180	7.8	98.8	10,500	8.9	2.46	.35	23.8
322C	18	900	70.4	14.8	5.1	1.06	.201	7.4	99.0	10,200	10.5	2.92	.39	25.3
328	18	800	78.9	11.8	3.4	.60	.202	4.4	99.3	8,500	7.1	1.69	.36	20.5
328	18	900	78.7	12.1	3.1	.65	.181	4.3	99.0	9,700	6.3	1.79	.20	19.2
Average[2]	18	900	68.8	-	-	-	-	-	-	10,710	13.9	3.20	.74	21.0

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. under a pressure of 30 inches of mercury.
2/ Average for 24 high-volatile A coals.
3/ The yield is low because the residual light oil in gas was not determined.

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TABLE 10. - Screen analysis of coke

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	Screen sizes, cumulative percent upon-				
			4-inch	3-inch	2-inch	1-1/2-inch	1-inch
a94A	18	800	82.7	94.0	97.3	98.5	99.2
a94A	18	900	54.0	79.5	93.2	97.2	98.6
a94A	slot	870-1,010	66.6	85.1	94.7	96.7	97.8
b316A	18	800	82.8	93.2	97.2	98.4	98.9
b316A	18	900	42.5	72.7	91.4	96.0	97.9
b316A	slot	870-1,010	51.4	83.2	94.7	96.8	97.9
336	18	800	74.8	89.0	96.5	98.5	99.6
336	18	900	33.1	63.6	87.1	95.1	98.1
336	slot	870-1,010	29.0	69.9	92.6	96.2	97.8
342A	18	800	77.7	91.8	95.5	97.6	98.6
342A	18	900	48.9	73.6	88.4	93.7	96.6
342A	slot	870-1,010	45.8	73.8	87.7	91.0	93.0
342B	18	800	74.1	91.2	96.7	97.4	98.3
342B	18	900	49.9	76.9	92.2	96.3	98.6
342B	slot	870-1,010	41.8	73.7	91.1	93.6	95.1

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TABLE 11. - Physical properties of coke

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
						2-inch screen	1-1/2-inch screen	1-inch screen	1/4-inch screen	2-inch screen	1-1/2-inch screen	1-inch screen	1/4-inch screen
93	13	600	1.57	0.78	50.3	65.3	81.1	90.9	96.9	4.6	24.6	51.3	66.0
93	13	700	1.74	.85	51.1	68.5	79.2	91.0	97.2	5.9	24.1	49.8	67.7
93	13	800	1.84	.89	51.6	59.8	83.1	93.6	98.2	8.4	32.3	58.1	71.8
93	18	900	1.88	.87	53.7	46.3	78.7	93.4	98.3	2.1	18.2	53.7	70.2
93A	18	900	1.91	.90	52.9	52.6	80.9	93.3	98.4	3.7	28.6	58.7	73.1
93B	18	900	1.90	.91	52.1	46.0	73.9	94.3	98.5	3.1	23.3	59.6	76.0
93	18	1,000	1.90	.88	53.7	15.3	50.1	85.2	98.0	.0	7.5	44.9	71.6
94	13	600	1.58	.72	54.4	50.9	61.4	82.7	95.5	.6	8.8	28.4	57.3
94	13	700	1.75	.78	55.4	58.6	66.8	80.3	95.7	1.0	5.8	24.0	61.9
94	13	800	1.79	.81	54.7	53.9	72.2	85.3	97.0	.0	9.7	32.4	66.0
94	18	900	1.90	.84	55.8	42.8	66.3	84.1	97.0	.5	9.9	38.2	70.0
94A	18	900	1.90	.83	56.3	50.4	74.5	88.3	97.4	2.6	20.5	46.9	70.0
94B	18	900	1.89	.86	54.5	58.0	80.8	92.2	98.3	6.4	28.1	55.0	73.1
94	18	1,000	1.89	.84	55.6	16.1	43.2	79.1	97.0	.0	3.5	34.3	74.4
322	18	900	1.88	.76	59.6	13.8	39.2	72.6	97.5	.0	1.7	32.5	74.3
322A	18	900	1.90	.81	57.4	37.3	68.4	89.6	98.4	.9	18.4	55.0	74.4
322B	18	900	1.90	.82	56.8	39.4	72.0	89.8	98.1	1.9	23.9	56.6	75.3
322C	18	900	1.89	.84	55.6	53.3	73.8	92.0	98.1	1.8	27.9	57.5	74.7
328	18	800	1.92	.94	51.0	79.6	93.3	97.1	98.8	30.0	61.8	70.7	73.7
328	18	900	1.96	.93	52.6	49.0	84.5	95.8	98.6	10.7	46.3	70.8	76.7
Average[1]	18	900	-	-	-	-	70.4	-	-	-	-	50.8	72.2

1/ Average for 25 high-volatile A coals.

Note: Results determined by the BM-AGA survey methods.

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TABLE 12. - Physical and chemical properties of gas

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	Specific gravity	Gross heating value[1] B.t.u. per cubic foot Determined	Gross heating value[1] B.t.u. per cubic foot Calculated	Gross heating value[1] B.t.u. per pound of coal	H_2S, grains per 100 cubic feet	Composition, dry, percent by volume CO_2	Illuminants	O_2	H_2	CO	CH_4	C_2H_6	N_2
93	13	600	0.547	795	757	1,750	450	3.6	2.7	0.4	31.6	5.3	49.0	6.4	1.0
93	13	700	.467	702	675	2,490	370	3.0	4.4	.4	43.6	5.6	37.4	4.5	1.1
93	13	800	.418	641	628	2,850	290	1.9	5.6	.4	50.3	5.9	32.8	2.1	1.0
93	18	900	.378	602	593	3,190	260	1.7	4.3	.4	53.2	6.1	33.4	.3	.6
93A	18	900	.357	587	577	3,050	240	1.5	3.8	.4	55.0	5.5	32.8	.0	1.0
93B	18	900	.349	581	568	2,960	230	1.5	3.6	.4	56.9	5.0	31.0	.4	1.2
93	18	1,000	.352	571	561	3,310	250	1.5	3.9	.4	56.5	6.3	30.2	.0	1.2
94	13	600	.578	824	787	1,710	520	4.8	4.0	.4	28.0	5.8	48.0	8.0	1.0
94	13	700	.480	705	684	2,360	380	3.3	4.5	.4	41.8	6.1	37.7	5.1	1.1
94	13	800	.424	647	623	2,780	300	2.3	5.3	.5	49.5	6.6	33.1	2.0	.7
94	18	900	.394	589	582	3,080	240	2.1	4.5	.3	52.6	7.0	31.7	.4	1.4
94A	18	900	.373	579	569	2,880	220	2.0	4.3	.4	55.3	5.8	30.6	.3	1.3
94B	18	900	.357	574	567	2,860	200	1.7	4.1	.4	56.7	5.7	29.3	.8	1.3
94	18	1,000	.370	562	562	3,180	230	1.9	4.4	.4	54.5	8.0	29.7	.0	1.1
322	18	900	.425	610	569	3,310	330	2.7	4.4	.4	50.7	9.7	30.7	.2	1.2
322A	18	900	.382	599	561	3,170	310	2.3	4.0	.4	53.6	8.2	30.4	.0	1.1
322B	18	900	.379	579	553	3,040	280	2.2	3.7	.4	55.3	7.6	29.7	.0	1.1
322C	18	900	.386	597	560	3,040	320	2.0	3.9	.4	55.3	6.6	30.5	.0	1.3
328	18	800	.370	627	614	2,660	250	1.1	3.6	.4	52.9	4.0	35.3	1.5	1.2
328	18	900	.330	585	582	2,840	230	.9	3.6	.4	57.3	3.9	32.8	.3	.8
Average[2]	18	900	.386	603	594	3,220	320	2.0	4.9	.4	52.6	6.6	31.2	1.1	1.3

1/ Stripped of light oil and saturated with water vapor at 60° F. and under a pressure equivalent to 30 inches of mercury.

2/ Average for 39 high-volatile A coals.

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TABLE 13. - Analysis of tar distillate and light oil

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	Distillate, percent by volume of dry tar			Neutral tar oil, percent by volume			Refined light oil from gas, percent by volume				Olefins in crude light oil from gas, percent by volume
			Acids	Bases	Neutral oils	Olefins	Aromatics	Paraffins and naphthenes	Benzene	Toluene	Paraffins	Solvent naphtha	
93	13	600	13.3	1.7	36.9	9.0	54.9	36.1	12.4	12.4	49.8	25.4	34.1
93	13	700	12.8	1.8	30.2	9.0	74.6	16.4	26.3	29.5	20.2	24.0	26.4
93	13	800	6.9	1.9	25.4	9.4	87.9	2.7	45.8	32.7	6.2	15.3	14.4
93	18	900	3.0	1.6	20.3	10.8	87.6	1.6	72.9	19.2	3.5	4.4	9.1
93A	18	900	2.8	1.4	18.9	10.6	88.0	1.4	73.4	19.2	4.2	3.2	9.3
93B	18	900	4.6	1.5	23.7	8.9	86.3	4.8	63.7	21.1	6.3	8.9	11.3
93	18	1,000	2.4	1.6	17.8	13.2	85.3	1.5	80.0	16.0	1.5	2.5	7.7
94	13	600	18.4	1.1	38.2	8.0	57.1	34.9	16.1	11.5	50.8	21.6	33.3
94	13	700	17.6	1.4	33.9	10.5	75.9	13.6	21.3	21.4	32.9	24.4	26.9
94	13	800	12.5	2.0	33.6	10.8	78.5	10.7	38.4	26.9	17.0	17.7	20.7
94	18	900	4.2	1.9	25.0	12.0	83.2	4.8	73.9	16.6	4.7	4.8	10.6
94A	18	900	9.9	2.3	32.5	11.0	86.8	2.2	63.0	20.8	7.9	8.4	13.3
94B	18	900	8.2	2.0	29.8	9.5	86.0	4.5	62.6	20.8	7.9	8.8	13.8
94	18	1,000	3.1	.7	18.0	11.6	87.2	1.2	79.7	15.0	2.4	2.9	7.8
322	18	900	7.1	2.2	26.1	10.0	89.1	.9	71.4	20.8	3.8	4.0	10.2
322A	18	900	5.7	2.4	26.0	10.0	89.3	.7	68.6	22.9	4.4	4.1	10.4
322B	18	900	5.6	2.8	24.2	10.0	89.3	.7	67.0	23.5	3.4	6.1	11.2
322C	18	900	7.6	2.6	26.4	11.5	87.2	1.3	65.0	23.4	4.8	6.8	12.0
328	18	800	4.5	1.4	30.2	8.8	81.5	9.7	41.4	31.7	9.2	17.7	17.1
328	18	900	2.2	1.1	24.0	9.6	87.3	3.1	61.5	24.6	3.9	10.0	12.2

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Chilton Coal

Chilton coal (93) yielded 70.9 percent coke at 900° C., and the yields of other products on the basis of per ton of coal were: Gas, 10,600 cubic feet; tar, 13.0 gallons; light oil in gas, 3.24 gallons; and ammonium sulfate, 20.2 pounds. Variation in the yields caused by changing the carbonizing temperature were normal for high-volatile A coals; maximum yields of 23.7 gallons of tar and 24.0 pounds of ammonium sulfate were obtained at 600° and 700° C., respectively. Blending with 20 and 30 percent Pocahontas No. 3 coal increased the yield of coke 2.6-3.6 percent and lowered the yields of other products. Physical test indexes of the 900° C. coke were: 1-1/2-inch shatter, 78.7; 1-inch tumbler, 53.7; and 1/4-inch tumbler, 70.2. The shatter and 1-inch tumbler indexes were appreciably higher than the averages for 25 high-volatile A coals, although the 1/4-inch tumbler index was lower than the average. Blending with 20 percent Pocahontas No. 3 coal raised the shatter and tumbler indexes significantly; the blend containing 30 percent low-volatile coal yielded stronger coke than that containing 20 percent, except that the 1-1/2-inch shatter index was lower.

Lower Cedar Grove-Alma A Coal

The Lower Cedar Grove-Alma A beds are mined as one because they are close together in the Omar No. 5 mine. The carbonization sample (94) contained 62.0 percent fixed carbon on the dry, mineral-matter-free basis, and its heating value was 14,840 B.t.u.; it ranks, therefore, as a high-volatile A coal. At 900° C. it yielded 69.4 percent coke; and, per ton of coal, the yields of other products were: Gas, 10,450 cubic feet; tar, 12.3 gallons; light oil, 3.18 gallons; and ammonium sulfate, 21.4 pounds. The yield of coke was 0.6 percent higher and the yield of tar 1.6 gallons per ton lower than the average yields for 18 high-volatile A coals; other yields were about the same as the averages. Variations in the yields caused by changing the carbonizing temperature generally were normal. Blending with Pocahontas No. 3 coal raised the yield of coke 2.6-4.3 percent and lowered the yields of the other products, except ammonium sulfate. Strength-test indexes of the 900° C. coke and the averages for cokes from 25 high-volatile A coals were, respectively: 1-1/2-inch shatter, 66.3 and 70.4; 1-inch tumbler, 38.2 and 50.8; and 1/4-inch tumbler, 70.0 and 72.2. This comparison indicates that Lower Cedar Grove-Alma A coal cokes less strongly than the average coal of similar rank; however, high-volatile coals generally are carbonized as blends with coals of higher rank; consequently, their individual coking powers are of secondary importance. Blending with Pocahontas No. 3 coal strengthened the coke appreciably, especially when 30 percent of that low-volatile coal was used. The heating value of the 900° C. gas was 589 B.t.u. per cubic foot or 3,080 B.t.u. per pound of coal.

Upper Elkhorn Coal

Upper Elkhorn coal (322) contained less fixed carbon than the two West Virginia coals (59.2 percent on the dry, mineral-matter-free basis); consequently, it yielded less coke and more gas. The yields at 900° C. were 64.8 percent coke; and, per ton of coal, the yields were: gas, 10,850 cubic feet; tar, 12.9 gallons; light oil in gas, 3.48 gallons; and ammonium sulfate, 23.5 pounds. The 900° C. coke had low 1-1/2-inch shatter and 1-inch tumbler indexes (39.2 and 32.5, respectively), although the 1/4-inch tumbler index (74.3) was high. These indexes were satisfactorily high for the blends with Pocahontas No. 3 coal (322A and 322B). The ternary blend, containing 20 percent Pocahontas No. 3 coal, coked more strongly when 30 percent

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Pittsburgh-bed coal (322C) was used. The heating values of the gas from 100 percent Elkhorn coal (610 B.t.u. per cubic foot and 3,310 B.t.u. per pound of coal) were high.

Palau No. 5 Coal

Palau No. 5 coal (328) was of medium-volatile rank and contained 13.2 percent ash on the as-carbonized basis, although it had been cleaned by the heavy-media process. It yielded 78.7 percent coke at 900° C., and the yields of other products per ton of coal were: Gas, 9,700 cubic feet; tar, 6.3 gallons; light oil in gas, 1.79 gallons; and ammonium sulfate, 19.2 pounds. The shatter and tumbler indexes of the coke were high, although some cokes of high ash content have low hardness factors or 1/4-inch tumbler indexes. The heating values of the gas were rather low as anticipated, because the ash content of the coal was high and the rank was medium-volatile.

Hill-Bed Coal, Cherokee County, Ala.

An investigation of Hill-bed[85/] coal from Hickey No. 1 mine on Lookout Mountain, Cherokee County, Ala., showed it to be of medium-volatile rank, low in ash and sulfur, and strongly coking. The coking power of high-volatile Pittsburgh-bed coal was increased significantly by blending it with 20 percent Hill coal; this blend should be safe to carbonize in by-product ovens because it developed a maximum pressure of only 1.7 pounds per square inch in the vertical expansion-test oven. Hill coal oxidized more rapidly than Pittsburgh coal from the Warden mine and required less oxygen to effect a given decrease in coke strength.

Comparative Tests in BM-AGA and 500-Pound Slot Ovens

The recently constructed 500-pound electrically heated oven was put into operation and used to carbonize five blends of coal at flue temperatures rising from 1,650° F. at the start to 1,810° F. at the end. The following blends were carbonized: 80 percent Corona and 20 percent Pocahontas No. 3 (b316A); a commercial-blend coke in by-product ovens at Pittsburgh, Pa. (336); 65 percent Elkhorn slack and 35 percent Pocahontas (342A); and 40 percent Elkhorn slack, 25 percent Elkhorn egg, and 35 percent Pocahontas (342B). The latter two blends (342A and 342B) are carbonized in industrial by-product ovens at Indiana Harbor, Ind. These blends also were carbonized by the BM-AGA method at 800° and 900° C. for comparison of yields and quality of products obtained by the two methods, the results of which are shown in tables 14 and 15.

The yields of coke were similar for the two test methods, except for blend 342A, which was about 2 percent lower in the 500-pound slot oven. The yields of gas on the percentage basis were higher, and the tar and ammonium sulfate yields were lower for the slot oven. The 900° C. BM-AGA yields check the slot-oven yields more closely than the 800° C. yields.

85/ Davis, J. D., Reynolds, D. A., Ode, W. H., Brewer, R. E., Wolfson, D. E., and Birge, G. W., Carbonizing Properties of Hill-Bed Coal from Hickey No. 1 Mine on Lookout Mountain, Cherokee County, Ala.: Bureau of Mines Tech. Paper 703, 1947, 40 pp.

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TABLE 14. - Yields of carbonization products, as-carbonized basis

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	Yields, percent by weight of coal[1]							Yields per ton of coal[1]				
			Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Gas, cubic feet	Tar, gallons	Light oil, gallons		$(NH_4)_2SO_4$, pounds
												In gas	Tar to 170° C.	
a94A	18	800	73.0	13.3	6.2	0.66	0.188	6.3	99.6	8,700	13.6	1.93	1.02	26.5
a94A	18	900	72.4	13.9	5.9	.87	.158	6.3	99.5	9,950	12.3	2.46	.72	21.7
a94A	Slot	870-1,010	72.8	14.2	4.2	.66	.137	5.4	97.4	9,800	8.8	1.80	.49	21.0
b316A	18	800	69.9	13.9	6.6	.80	.170	8.2	99.6	8,650	13.9	2.28	.96	30.3
b316A	18	900	69.4	14.6	6.0	.98	.162	7.6	98.7	9,800	12.6	2.73	.81	30.1
b316A	Slot	870-1,010	70.5	15.2	4.4	.57	.116	7.8	98.6	9,950	9.0	1.56	.57	23.7
336	18	800	69.6	13.1	6.6	.71	.169	8.7	98.9	8,600	14.0	2.02	1.05	25.3
336	18	900	69.3	13.8	6.2	.97	.146	8.7	99.1	9,900	12.9	2.69	.71	22.0
336	Slot	870-1,010	69.6	13.1	5.4	.66	.130	8.5	97.4	8,930	11.1	1.79	.84	20.6
342A	18	800	74.0	13.7	4.3	.70	.178	5.9	98.8	9,250	9.5	1.93	.44	23.9
342A	18	900	73.4	14.6	4.1	.90	.148	7.3	100.4	10,400	8.4	2.46	.35	21.1
342A	Slot	870-1,010	71.5	16.6	3.5	.70	.095	7.7	100.1	10,650	7.2	1.92	.31	17.8
342B	18	800	72.2	13.6	4.4	.67	.186	7.9	99.0	9,100	9.3	1.88	.46	25.4
342B	18	900	71.7	14.4	4.0	.78	.146	7.1	98.1	10,350	8.2	2.14	.38	19.7
342B	Slot	870-1,010	72.5	14.2	3.5	.69	.129	7.2	98.2	9,650	7.2	1.90	.36	20.6

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.

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TABLE 15. - Physical properties of coke

Coal No.	Retort diameter, inches	Carbonizing temperature, °C.	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon- 2-inch screen	Shatter test, cumulative percent upon- 1-1/2-inch screen	Shatter test, cumulative percent upon- 1-inch screen	Shatter test, cumulative percent upon- 1/ 1/4-inch screen	Tumbler test, cumulative percent upon- 2-inch screen	Tumbler test, cumulative percent upon- 1-1/2-inch screen	Tumbler test, cumulative percent upon- 1-inch screen	Tumbler test, cumulative percent upon- 1/2-inch screen	Tumbler test, cumulative percent upon- 1/ 1/4-inch screen
a94A	18	800	1.87	0.86	54.0	85.5	92.8	96.4	98.4	11.5	31.4	44.5	50.3	50.9
a94A	18	900	1.94	.87	55.2	63.4	84.0	94.8	98.2	1.8	15.3	40.5	57.9	60.8
a94A	Slot	870-1,010	1.91	.86	55.0	80.2	90.3	95.5	98.2	5.3	21.4	42.2	55.5	57.4
b316A	18	800	1.91	.81	57.6	79.8	91.0	94.4	98.4	22.5	49.1	59.8	-	2/66.1
b316A	18	900	1.95	.81	58.5	66.8	85.7	93.9	97.7	.7	16.4	44.0	58.2	60.2
b316A	Slot	870-1,010	1.93	.84	56.5	80.3	90.8	95.8	98.4	6.1	23.9	44.1	53.7	55.3
336	18	800	1.90	.84	55.8	78.6	90.5	95.7	98.1	5.0	32.3	53.4	59.8	60.5
336	18	900	1.91	.86	55.0	50.5	81.7	94.7	98.3	.7	15.8	49.6	63.9	65.5
336	Slot	870-1,010	1.90	.87	54.2	67.5	88.2	95.4	98.3	2.5	21.7	50.9	60.6	61.9
342A	18	800	1.86	-	-	79.3	89.6	95.2	97.7	3.2	28.0	50.3	59.6	60.5
342A	18	900	1.91	.83	56.5	62.9	80.3	93.2	97.1	1.0	10.2	38.0	55.5	61.9
342A	Slot	870-1,010	1.92	.85	55.7	72.6	87.6	94.4	97.3	1.7	13.5	42.5	55.7	57.2
342B	18	800	1.87	.84	55.1	77.5	91.7	95.9	98.1	8.3	32.3	52.7	59.3	59.9
342B	18	900	1.90	.85	55.3	44.7	75.3	93.8	98.1	.0	9.0	44.9	65.2	67.5
342B	Slot	870-1,010	1.89	.84	55.6	68.9	86.2	94.7	98.0	1.2	15.7	45.8	59.1	60.6

1/ Actually 0.261-inch screen.
2/ 1/4-inch screen.

Note: Results determined by the American Society for Testing Materials methods.

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The physical properties of the slot-oven cokes generally were intermediate between the 800° and 900° C. BM-AGA cokes. The 800° C. cokes were of larger size, and their 1-1/2-inch shatter and 1-inch tumbler indexes were higher; these differences generally were reversed for the 900° C. cokes, although a comparison of sizes shows that some of the slot-oven cokes were smaller than either BM-AGA coke. The average 1/4-inch tumbler index, hardness factor, for the five slot-oven cokes was 58.5, which is less than the averages for the 800° and 900° C. BM-AGA cokes (59.6 and 63.2, respectively), although this index was lowest for three 800° C. cokes. Table 9 shows no significant differences in the true or apparent specific gravities of cokes obtained by the two methods.

Swelling Properties of Coal During the Coking Process

The sole-heated oven was used in 60 tests, and the large vertical oven in 16 tests to determine the expanding properties of coals from 16 different beds and of 8 blends described in table 7. All large vertical-oven tests were made at a wall temperature equivalent to 2,300°-2,500° F. flue temperature. The expanding properties are given in table 16.

TABLE 16. - Expansion properties of coals

Coal No.	Test moisture, percent	Average test bulk density, lb. per cubic foot	Sole-heated oven expansion, percent		Large vertical oven, maximum pressure on movable wall, lb. per square inch[2]
			At 55.5 lb. per cubic foot[1]	Dry solid coal	
93	1.9	53.39	-20.3	19.6	-
a93	1.9	53.22	[3]-19.7	20.4	-
b93	1.8	53.54	[3]-20.0	20.8	-
c93	1.8	53.21	[3]-24.6	13.8	-
93A	1.9	53.34	- 7.9	40.2	-
93B	1.8	53.31	- 4.3	45.7	-
94	2.7	53.68	-11.3	37.1	-
a94	2.2	52.97	[3]- 5.5	42.2	-
b94	1.9	53.73	[3]- 8.4	37.4	-
c94	2.3	53.57	[3]- 7.7	39.0	-
d94	2.2	53.51	[3]- 7.7	39.9	-
e94	1.9	53.40	[3]- 6.4	41.5	-
94A	2.6	53.28	- 4.0	49.0	-
94B	2.6	53.38	- .5	55.0	-
322	4.7	52.91	- 9.5	41.8	-
322A	3.9	52.72	- 6.3	45.7	-
322A	3.7	49.79	-	-	0.45
322B	3.7	53.31	- 3.5	50.8	-
322B	3.7	50.09	-	-	.45
322C	3.1	53.33	- 4.6	47.0	-
322C	3.1	50.49	-	-	.50
323	2.9	53.27	[3]- 4.0	48.7	-
323	2.9	49.40	-	-	4.6
323	2.9	49.18	-	-	1.8

See footnotes at end of table on following page.

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TABLE 16. - Expansion properties of coal (con.)

Coal No.	Test moisture, percent	Average test bulk density, lb. per cubic foot	Sole-heated oven expansion, percent		Large vertical oven, maximum pressure on movable wall, lb. per square inch 2/
			At 55.5 lb. per cubic foot 1/	Dry solid coal	
323A	3.4	52.85	-20.4	24.0	-
323A	3.4	49.78	-	-	.9
323A	3.3	51.79	-	-	.5
324	3.6	53.24	3/-21.2	22.1	-
325	3.1	54.00	3/-23.6	20.3	-
326	3.6	53.73	3/- 7.8	45.0	-
326	3.0	53.55	3, 4/- 2.1	51.9	-
326	3.1	53.21	3, 5/+ .2	55.6	-
326	3.6	49.40	-	-	1.5
326	3.6	51.19	-	-	1.5
a326	2.7	53.22	3/+ 5.5	52.7	-
a326	2.7	49.66	-	-	3.8
327	2.9	52.95	3/-28.1	12.3	-
331	2.0	53.16	3/- 7.6	41.9	-
331	2.0	52.68	-	-	1.5
335	2.2	54.56	3/-13.5	33.0	-
335	2.4	53.39	3, 6/- 7.3	44.0	-
335	2.4	50.80	-	-	6/3.1
335	2.4	52.41	-	-	3.7
332	.6	53.58	+12.1	63.8	-
333	1.4	55.25	+ 5.8	61.2	-
334	.8	53.69	-12.1	33.4	-
b328	1.6	54.59	- 4.0	51.3	-
328A	1.9	54.07	3/- 3.6	51.2	-
328A	5.9	52.14	3/- 5.8	54.0	-
328A	6.3	53.60	3/- 7.5	51.8	-
328A	2.0	53.14	-	-	4.2
328A	5.9	48.66	-	-	1.7
328A	6.3	47.46	-	-	1.3

1/ End of test contraction for contracting coals; maximum expansion for expanding coals.
2/ Each large vertical-oven test reported individually.
3/ Single tests.
4/ Tested after 5 months' storage.
5/ Tested after 5 months' storage and size reduction.
6/ Tested after size reduction.

Two special samples of Chilton-bed coal (c93) and (b93) from different parts of the Lorado No. 5 mine, one sample (c93) from a prospect hole in the Chilton bed, and the BM-AGA sample (93) were tested to determine whether or not any variation in the expanding tendency existed in coal from various parts of the mine. The two special expansion samples from the mine agreed very closely with the BM-AGA sample, whereas the sample from the prospect hole contracted slightly more. The blends of Chilton-bed coal with Pocahontas No. 3 coal (93A and 93B) contracted to a smaller extent.

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Alma A coal (bottom bench-b94) was found to have greater contraction than the Lower Cedar Grove (top bench-a94) or any of the combined special samples (c94, d94, and e94) from different data of the mine, but not greater than the BM-AGA combined sample (94). The 80:20 blend with Pocahontas No. 3 coal (94A) contracted 4.0 percent; the 70:30 blend (94B) was almost neutral, contracting only 0.5 percent.

A sample of Elkhorn No. 3 (322) from a prospect hole in Knott County, Ky., was tested in the sole-heated oven. The 80:20 and 70:30 blends of this coal with Pocahontas No. 3-bed coal (322A and 322B) and a 50:30:20 blend of Elkhorn No. 3-, Pittsburgh-, and Pocahontas No. 3-bed coals (322C) were tested in both the sole-heated and large vertical expansion ovens. The 100-percent coal and the blends contracted in the sole-heated oven; none of the blends exerted over 1.0 pounds per square inch pressure in the large, vertical oven.

In a search for new coals for gas-making purposes, the expanding properties of eight samples were determined. The coals ranged from 29.0 to 36.6 percent volatile matter (moisture-free basis). The expanding properties of these coals were desired because coals within this range of volatile matter may exert dangerous pressures on coke-oven walls during carbonization. Lower Freeport bed coal, Kramer mine (323), the resample of Lower and Upper Freeport bed coal, Kent Nos. 1 and 2 mines (a326), and Upper Freeport bed coal, Ernest mine (335), exerted over 2.0 pounds pressure per square inch in the large vertical oven, which would be unsafe for commercial use according to the arbitrary limit of 2.0 pounds per square inch as the maximum safe expansion pressure. The variation in the expanding tendency of the two samples of Upper Freeport-bed coal is not unusual for this coal. The reason for the increase in expansion pressure of the resample of Kent No. 1 and 2 (a326) is not known, but the necessity for a constant check on the expansion of Freeport coals used in industry is indicated by this difference in two samples from the same mine.

During the fiscal year 1945, sole-heated-oven tests were made for Rochester Gas & Electric Co. on two of the coals tested this year; Pittsburgh bed, Banning No. 1 mine (342), and Lower and Upper Freeport bed, Kent Nos. 1 and 2 mines (326). The expansion results are: Banning No. 1 (1945), 23.1 percent contraction and (1948), 21.2 percent contraction; Kent Nos. 1 and 2 (1945), 3.0 percent maximum expansion and 2.0 percent contraction at end of test, (1948) original sample (326), 7.8 percent contraction at end of test, and resample (a326), 5.5 percent maximum expansion and 0.5 percent contraction at end of test. Sole-heated-oven tests were made on the resample of Kent Nos. 1 and 2 (a326) after 5 months' storage in closed steel drums, and the contraction decreased from 7.8 to 2.1 percent; and, after crushing of the stored coal to a finer size, it expanded 0.2 percent.

A byproduct plant which operates a gas-fired Bethlehem tester at a constant flue temperature of 2,350° F. submitted three samples of coal (332, 333, and 334) for comparison of its Bethlehem tester with the Bureau of Mines sole-heated oven. The byproduct plant air-dries its sample at 105° C. overnight and obtains a test bulk density of 55.0 pounds per cubic foot. The closest agreement between the two experimental ovens was obtained when the Bureau of Mines expansion results were calculated to 55.5 pounds per cubic foot of dry coal. Results obtained by the byproduct plant and the Bureau of Mines were, respectively: Coal 332, 13.2 and 12.8 percent expansion; 333, 7.5 and 7.3 percent expansion; and 334, 13.2 and 12.1 percent contraction, or differences of 0.4, 0.2, and 1.1 percent. These differences are only of the order of differences between duplicate tests. The expansion results given in table 16 for these coals are reported on the basis of 55.5 pounds per cubic foot of coal, with moisture content as tested.

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One sample of 2- by 1/4-inch coal (b328) from the Palau No. 5 mine, Coahuila, Mexico, was tested in the sole-heated oven for comparison with a blend (328A) consisting of 45.9 percent 2- by 1/4-inch coal (328) and 54.1 percent 1/4- by 0-inch coal (a328). The blend contracted 3.6 percent, and the special expansion sample for comparison contracted 4.0 percent. The 1/4- by 0-inch coal contained 2 percent less ash than the 2- by 1/4-inch sample.

The bulk density in the first large vertical oven test on Palau No. 5 mine coal was high, and the pressure exceeded the limit of the oven, making it necessary to allow lateral expansion of the charge. In later sole-heated and large vertical-oven tests at lower bulk densities obtained by the addition of moisture, wall pressures in the vertical oven were reduced greatly. The coke yield, apparent specific gravity, and percentage of coke remaining on a 4-inch screen for the Palau-coal blend (328A) were lowered by the addition of moisture to the coal, but the coke-strength indexes were all very high. The coke from coal 328A had a real specific gravity of 1.98.

Four sole-heated oven tests of Mary Lee coal in a finer size than used in the original tests showed that the contraction decreased with decreasing particle size.

One sole-heated-oven charge (Pittsburgh-bed coal) was removed after 3 hours' coking to study the plastic layer. The average thickness of the coked layer was 1-1/2 inches. The thickness of the plastic layer ranged from 1/4- to 1/2-inch.

The accumulated data[86] obtained with a small vertical-expansion oven were reported. The oven is a small replica of the large vertical-slot oven, the charge being only 17 pounds as compared with 350 pounds for the large oven and its thickness being 5 inches instead of 10. The small oven gave high, erratic results, mainly because of the thickness of charge. It was concluded that it would be difficult to predict from results obtained in an oven of this size, the pressures a sample would develop in a large oven, or to state definitely that a borderline coal would be safe or dangerous for industrial use.

Plasticity of Coals

Plastic properties of 26 of the bituminous coals and 16 of the bituminous coal blends described in table 7 were determined during the fiscal year. Two or more tests on the same sample were usually made by the Gieseler-plastometer and by the Davis-plastometer methods. A total of 189 tests - 96 by the Gieseler method and 93 by the Davis method - were made. Twenty of the coals tested were high-volatile A, two were medium-volatile, and four were low-volatile bituminous coals. Eleven blends were in the high-volatile A group and five blends were in the medium-volatile group.

Unless modified by unusual chemical composition or by oxidation, the plastic properties of coals vary with rank. In general, the characteristic temperatures - at which fusion, maximum fluidity, and resolidification occur - are increased, the degree of fluidity (Gieseler method) is decreased, and the maximum resistance (Davis method) is increased with change of rank of coal from high-volatile A, through medium-volatile, to low-volatile.

86/ Naugle, B. W., Davis, J. D., McCartney, J. T., and Wilson, J. E., Measurement of Coking Pressure in a Small Laboratory Oven: Bureau of Mines Rept. of Investigations 4285, 1948, 15 pp.

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The maximum fluidity of a blend depends on its constituent coals and their relative proportions, and may be intermediate or higher than the maximum fluidities of the individual coals. Limits for plastic characteristics of coals and blends chosen according to classification by rank will be arbitrary because of some overlapping.

The plastic properties of each of the 26 coals and of the 16 coal blends tested are here summarized:

Coal name, number, and rank	Plastic properties
Chilton (93) high-volatile A.	Typical of coals of this rank.
Blend of (93) and 20 percent Pocahontas No. 3 (75) low-volatile.	Characteristic temperatures raised increased maximum resistance, increased maximum fluidity.
Blend of (93) and 30 percent Pocahontas No. 3 (75) low-volatile.	Characteristic temperatures raised, increased maximum resistance, decreased maximum fluidity.
Lower Cedar Grove-Alma A (94) high-volatile A, and resample (a94).	Similar to coal (93) except for lower maximum fluidity and lower maximum resistance.
Blend of (94) with 20 and 30 percent Pocahontas No. 3 (75) low-volatile.	Increased characteristic temperature over (94), sharply decreased maximum fluidity, markedly increased maximum resistance.
Corona (b316) high-volatile A; lower in rank than (94).	Typical of coal of this rank; resistance ended at lower temperature than (94).
Blend of (b316) with 20 percent of Pocahontas No. 3 (75) low-volatile.	Slightly higher characteristic temperatures than (b316), appreciable fluidity, and higher maximum resistance.
Pocahontas No. 3 (317) low-volatile.	Typical of coal of low-volatile rank.
Blend of (317) with 80 percent Pittsburgh (28) high-volatile.	Markedly decreased characteristic temperatures as compared to (317), sharply increased maximum fluidity, markedly decreased maximum resistance.
Upper Elkhorn No. 3 (322) high-volatile A; (low in this rank).	Typical behavior with low maximum fluidity and low maximum resistance.
Resample of (322) cleaned at 1.50 specific gravity, 60-mesh size.	Closely checked (322).
Blend of (322) with 20 percent (322A) and with 30 percent (322B) Pocahontas No. 3 (75) low-volatile.	Characteristic temporarily not appreciably effected by maximum fluidity lowered and maximum resistance increased, especially with 30 percent blend.

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Coal name, number, and rank	Plastic properties
Blend of (322) 50 percent, (75) 20 percent and Pittsburgh (28) high-volatile A 30 percent.	Maximum fluidity increased of (322) maximum resistance higher than for (322) and for (322A) and lower than (322B).
Lower Freeport (323) high-volatile A.	High maximum fluidity and maximum resistance and strong free swelling (Gieseler method).
Blend of 40 percent of (323), 30 percent each of (324) and (325); blend (323A).	Lower maximum fluidity and higher maximum resistance than (323).
Pittsburgh bed (324) high-volatile A and Pittsburgh bed (325) high-volatile A.	Generally typical of coals of this rank but (324) came more fluid and gave slightly higher maximum resistance than the strong free-swelling coal (325).
Lower Upper and Freeport coal (326) high-volatile A and resample (a326) from new area, high-volatile A.	Strong free swelling properties; (326) showed lower maximum fluidity, and slightly lower maximum resistance than (a326).
Resamples of (326), No. 326-S-2 and 326-S-3, after storage 6 months.	Characteristic temperatures and maximum fluidity increase; maximum resistance decreased; (326-S-3) strongly free-swelling.
Thick Freeport (327) high-volatile A.	Plastic properties typical of coal of this rank.
Blend (328A) of two screened fractions of Coahuila, Mexico, high-volatile A.	Appreciable fluidity and high maximum resistance for coal of this rank.
Upper Freeport (331) high-volatile A.	Typical plastic properties except for strong free swelling.
Sewell (332) low-volatile (lower in rank than Pocahontas No. 6).	Much higher fluidity and lower maximum resistance than Pocahontas No. 6.
Pocahontas No. 6 (333) low-volatile.	Typical plastic properties for its rank.
Pittsburgh (334) high-volatile A.	Very high fluidity and low maximum resistance.
Upper Freeport (335) and (335-S-2) medium-volatile.	Very high fluidity and appreciable maximum resistance.
Blend used in byproduct ovens at Pittsburgh, Pa. (336).	Good fusion, high maximum fluidity, and appreciable maximum resistance.
Lower Thacker (338) high-volatile A.	Similar to plastic properties of (334).
Pocahontas coal (341) low-volatile.	Typical plastic properties of this rank coal.

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Coal name, number, and rank	Plastic properties
Upper Elkhorn No. 3 slack (342) high-volatile A.	Showed evidence of being partly oxidized; maximum fluidity lower than same coal tested previously.
Blend of (342) with 35 percent Pocahontas (341).	Higher fluidity and lower maximum resistance than either of coals used.
Blend (342B) of 40 percent (342), 35 percent (341), and 25 percent Elkhorn egg (343) high-volatile A.	Slightly lower fluidity and appreciably higher maximum resistance than (342A).
Elkhorn egg (343) high-volatile A.	Typical of coals this rank; no resistance in Davis plastometer tests.
Corban (344) high-volatile A.	Similar to (343), except somewhat more fluid.
Blend (344A) of 65 percent Corban (344) and 35 percent Pocahontas (341).	Intermediate to those of its constituent coals; no resistance in Davis plastometer tests.
Blend (344B) of (344) 50 percent; (341) 35 percent; and (343) 15 percent.	Plastic properties similar to those of (344); no resistance in Davis plastometer tests.

Effect of Oxidation on Carbonizing Properties of Pocahontas Coal

The effects of oxidation upon the carbonizing properties of Pocahontas No. 3- and No. 4-bed[87] coals were determined, and a second (pillar) sample from the No. 3 bed was studied to determine whether its coking properties had been altered by oxidation in place. No. 4 coal oxidized more rapidly and probably would lose its coking power first if both coals were stored under identical conditions. The pillar sample yielded 21 percent less tar than the tipple sample from the same bed, and tumbler tests showed that the coke from the pillar coal was more abradable. These results indicate that the pillar coal may have been oxidized enough to diminish its coking propensity.

Oxidizing Properties of Bituminous Coals

The effects of oxidation at room temperature and at 99.3° C. on 11 coking coals representing 9 beds were determined by agglutinating tests, chemical analyses, and carbonization tests at 800° C. of both fresh and oxidized samples.[88] In general, continued oxidation of the coal decreased the agglutinating value, carbon and hydrogen contents, and heating value and increased the real specific gravity and oxygen

87/ Davis, J. D., Reynolds, D. A., Brewer, R. E., Naugle, B. W., and Wolfson, D. E., Effect of Oxidation Upon the Carbonizing Properties of No. 3- and No. 4-Bed Coals from Eastgulf, Raleigh County, W. Va.: Bureau of Mines Tech. Paper 702, 1947, 18 pp.

88/ Brewer, R. E., Reynolds, D. A., Steiner, W. A., and Van Gilder, R. D., Carbonizing Properties of Coking Coals, Effect of Oxidation in Storage: Ind. Eng. Chem., vol. 40, No. 7, 1948, pp. 1243-1254.

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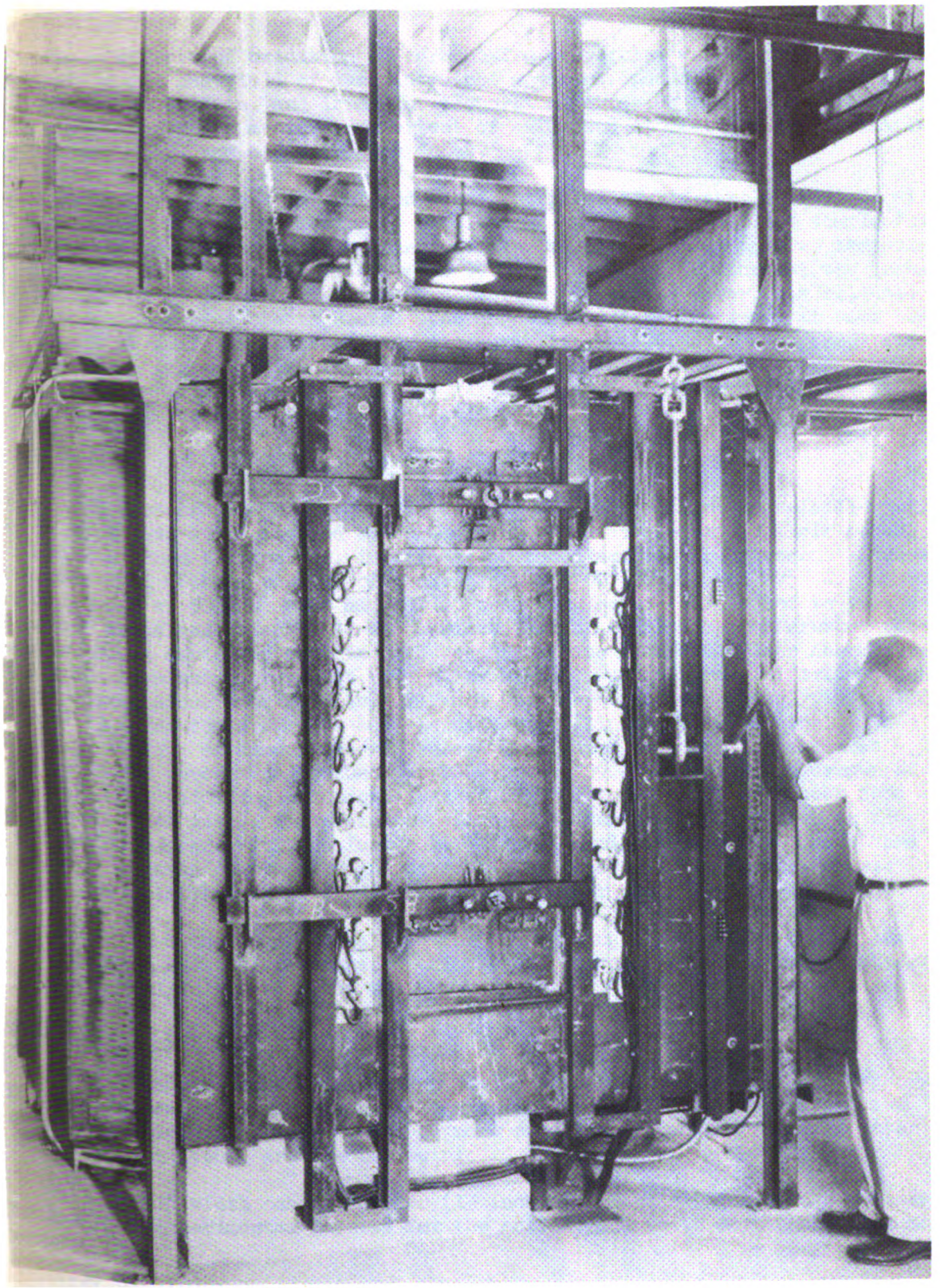

Figure 29. - Coke end of Bureau of Mines experimental coke oven.

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content. The effects of oxidation on carbonizing properties were decreased strength and fusion of coke and yield of tar, increased apparent specific gravity of coke and yield of ammonium sulfate, and irregular proportions of acids and residual pitch in tar. The most sensitive measures of extent of oxidation of coal were agglutinating value, yield of tar, and coke-strength index.

Correlation of changes in coal and coke properties of the sample oxidized at room temperature with those of samples oxidized at 99.3° C. established simple factors that could be used to express relative rates of oxidation at the two temperatures. The number of days of oxidation at 99.3° C. required to decrease the coke-strength index by 15 percent, defined as durability of coking power, was selected as a basis for comparing the 11 coals. The durability of coking power at room temperature of each coal was computed from its durability at 99.3° C. by appropriate factors based on its agglutinating value and strength indexes of its cokes. The durability of the 11 coals, thus obtained, afforded a good indication of the known commercial storage behavior of the coals studied.

Desulfurization of Coal and Coke

Increased conversions of the sulfur in coal and coke samples to volatile sulfur products in the gas were obtained by carbonizing coals and reheating their cokes, first cooled to room temperature, in streams of added ammonia or hydrogen. Series of tests with and without passage of these gases at 700°, 800°, and 875° C., at room temperature, and at 500° C. were made on 15-gram samples of coal, sized to pass a No. 20 and be retained on a No. 40 U. S. sieve, and on their lump and crushed cokes. The desulfurizing action of ammonia gas, because of its almost complete decomposition into hydrogen and nitrogen at 800° C. or higher, was much more effective than that of hydrogen alone; for example, 67.2 and 48.8 percent, respectively, with lump coke at 800° C., as compared with 46.7 percent for Illinois No. 6 bed coal. This desulfurizing effect of ammonia was increased when added at lower temperatures - for example, 67.8 percent for ammonia at 500° C. and 59.2 percent for hydrogen at room temperature. Addition of ammonia gas at 800° C. to 0- to 20-mesh coke from a Pittsburgh-bed coal gave a conversion to volatile sulfur of 62.3 percent, as compared with 60.0 percent with the lump coke. Addition of nitrogen gas to coal and coke samples, because of its diluting action in the carbonization gases, showed lower conversions to volatile sulfur products than in similar tests without added gas.

Quantitative methods were developed for determining the volatile sulfur compounds - hydrogen sulfide, mercaptans, thiophenes, carbon disulfide, carbon oxysulfide, and residual sulfur - in the gas.

New Experimental Coke Oven

A new experimental coke oven designed and constructed at the Southern Experiment Station, Tuscaloosa, Ala., is shown in figure 29. Among the features of the new Bureau of Mines experimental oven, one or more of which are absent from all other known experimental ovens, are the following:

(1) Full-width coking chamber (17 inches). This eliminates the necessity of adjusting the experimental results for the estimated effects of thinner than normal charges.

(2) Heating walls are constructed of silica brick of average oven-wall thickness (4-1/2 inches). The new experimental oven, therefore, can be operated

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at any desired flue temperature and thus directly match the usual industrial practice in this respect. This feature eliminates the necessity for estimating temperature-progression curves for operation of the experimental oven and eliminates all errors arising from such estimates. Correlation between the quality of cokes produced in the experimental oven and those produced in full-scale ovens should be greatly simplified.

(3) Zoned heat-input arrangements are used so that the entire heating wall(s) can be maintained at any desired uniform temperature. The arrangements also permit temperatures to be varied from top to bottom, to make it possible to match the inherent characteristics of any particular battery of coke ovens, should such action be found desirable.

(4) The "movable" wall of the oven is suspended; the design is such that movements far in excess of those allowed during a coking test would require only a negligible force. (A pressure of 0.01 pound per square inch would move the unrestrained wall about one-eighth inch, whereas the maximum movement allowed under operating conditions is less than 0.02 inch.) All forces exerted by the coking charge, therefore, are actually transmitted to the recording mechanism and pressure losses due to friction or accidental blocking of moving parts are avoided.

(5) Pressure detecting and recording mechanisms are standard equipment purchased on the open market; no fine alinement or delicate adjustment is required to install or operate them.

(6) The oven is designed for coking pressures up to 10 pounds per square inch. This larger range of allowable coking pressure permits systematic investigation of the blending properties of coals and the underlying fundamentals over a wider range of blends than is possible with ovens having lower coking-pressure capacities.

Because of these and other features of design, the new oven will be useful in determining the significant effects of many known operating variables on the quality of coke. Among these, to name a few, which have not been satisfactorily investigated because of lack of suitable apparatus, are variations in flue temperature, moisture in charge, and tempering time.

However, these points of utility are in addition to the primary purpose of the oven - that is, to have available for use in determining the blending properties of coals, an experimental oven which is in all essential respects a small section of a modern industrial byproduct oven.

Low-Temperature Carbonization in Japan

The results of a field survey made of commercial low-temperature carbonization processes used in Japan before and during World War II, including a complete description of the processes employed and plants examined, have been published.89/

89/ Reid, William T., Low-Temperature Carbonization of Coal in Japan: Bureau of Mines Inf. Circ. 7430, 1948, 82 pp.

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GASIFICATION

Gasification of Subbituminous Coal and Lignite

The results of investigations on gasification of low-rank coals from 1943-47 were analyzed and summarized.20/ Fundamental theories of gasification of coal in externally heated retorts were reviewed and the important aspects of heat transfer at high temperature were presented.

Analysis of data obtained on the large plant at Grand Forks, N. Dak., and the small pilot plant at Golden, Colo., indicated that further experimental work is necessary to improve operation of the annular retort. Some troubles were experienced in the large plant in the building up of ash deposit on the inner surface of the alloy retort when one grade of natural lignite was gasified, but these troubles were not noted in the small pilot plant when other grades of coal were gasified. The experimental data show that heat was transferred at a rate of about 5,000 B.t.u. per hour per square foot in the small pilot plant, corresponding to 70 to 80 cubic feet of water gas made per hour per square foot. The performance data on the pilot plants indicate that heat is transferred through the retort wall at over-all thermal efficiencies of about 60 percent. This is exceptional because the ordinary methods of heating retorts at high temperatures, employing conventional gas burners, indicate thermal efficiencies of only 30 percent. Because of the high heat-transfer efficiency attained in the retort developed by the Bureau of Mines, it is probable that such a heating system might be used effectively in the fluidized gasification of coal. Rates of heat transfer in the range of 10,000 B.t.u. per hour per square foot might be attained through the wall containing a fluid bed, and this would correspond to gas-production rates of 125 cubic feet per hour per square foot, which indicates that the 48-inch-diameter retort should have a production capacity of about 25,000 cubic feet of synthesis gas per hour. Such rates of production would make the process attractive for commercial production of water gas from subbituminous coal and lignite and should compete favorably with gasification systems using oxygen.

At Golden, Colo., limited experimental work was conducted on the gasification of coal and char dusts in suspension as a means of furnishing producer gas for heating the externally heated retorts. A small pilot plant of 4,000 cubic-feet-per-hour capacity was operated successfully on several tests.

Gasification of Lignite for Preparation of High-Hydrogen Water Gas

During the past fiscal year the Grand Forks, N. Dak., Pilot Plant produced a high-hydrogen water gas with a hydrogen : carbon monoxide ratio of 9. The plant was operated more than 1,600 hours, during which time some 570,000 pounds of lignite was processed and almost 13,000,000 cubic feet of gas made. This quantity of gas represents over 7,500,000 cubic feet of pure hydrogen, or between 25,000 and 35,000 cubic feet per ton of raw lignite gasified.

The gas by this process, particularly that with the higher hydrogen : carbon monoxide ratios, can be used directly for the partial or complete reduction of iron ores. The ore may be partly reduced to the magnetic oxide form for magnetic concentration, or it may be completely reduced to sponge iron or iron powder. After removal

20/ Parry, V. F., Wagner, E. O., Koth, A. W., and Goodman, J. E., Gasification of Subbituminous Coal and Lignite in Externally Heated Retorts; Ind. Eng. Chem., vol. 40, No. 4, 1948, pp. 627-641.

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of carbon dioxide, the partly purified gases, particularly those with the lower hydrogen : carbon monoxide ratios, may be used as synthesis gases for the production of liquid fuels by the Fischer-Tropsch process or for the industrial preparation of synthetic organic compounds. By a further step, the carbon monoxide can be reacted with steam to obtain commercially pure hydrogen, which may be used in converting solid fuels into liquid fuels by the Bergius process, for production of ammonia and fertilizers, for hydrogenation of fats, and for other industrial uses.

Retort Corrosion During Gasification

The problem of retort corrosion during the gasification of lignite was analyzed. The economics of the process depends upon the life of the outer metal cylinder, through which flows the heat energy needed to maintain the reaction and which forms the outer wall of the reaction chamber. This cylinder is subject to severe operating conditions. It is maintained at a temperature between 1,400° and 2,100° F. At the same time, the outer surface of the cylinder is in contact with flame and combustion gases, while the inner surface is in contact with steam, hot carbon, and reducing gases, ash, sulfur compounds, and hydrocarbon vapors. The solution of this problem is imperative because a short retort-tube life will markedly increase the cost of gas production.

It was concluded that, as a result of more than 3,000 hours' operation, a Pluramelt outer cylinder (a metallic sandwich consisting of a 3/8-inch mild-steel center between two 1/8-inch layers of 26-percent chromium alloy) will give at least the expected life of 10,000 operating hours if the operating temperature does not exceed 1,900° F. if local superheating does not occur and if the oxidation caused by the reaction of excess steam with the chromium is reduced. It was determined further that, when using Pluramelt tubes, welds should be made with a 310 chrome-nickel alloy.

A similar investigation, based upon over 400 hours of operation, showed that "metcollized" metal was not a satisfactory material under these conditions.

These investigations are being extended to include other possible materials of construction.

Coal Investigations in Germany

Members of technical fuel missions to Germany organized under the auspices of the Technical Industrial Intelligence Committee have written a large number of reports describing German developments in mining, preparation, and utilization of coal. These reports are on file at the Bureau of Mines, Washington, D. C., where they are available for public examination. Because of the importance of the subject material, some of the reports or combination of reports were published.

Processing of high-temperature tar, utilization of the products obtained, and information concerning new and improved processes or products were obtained from visits to 40 targets in the American, British, French, and Russian zones of occupation.91/ Certain gas-making processes used in Germany differ considerably from those in common use in America. Those investigated were92/ the Lurgi pressure-gasification, Winkler, and Leuna slagging-type gas-producer processes, using steam

91/ Rhodes, E. O., German High-Temperature Coal-Tar Industry: Bureau of Mines Inf. Circ. 7409, 1947, 117 pp.

92/ Odell, William W., Gasification of Solid Fuels in Germany by the Lurgi, Winkler, and Leuna Slagging-Type Gas-Producer Processes: Bureau of Mines Inf. Circ. 7415, 1947, 46 pp.

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and oxygen as the gas-making fluids. Observations were made on coking practice in Germany in preparation of metallurgical coke and the use of the sloping type of Didier gravity-discharging coke oven.93/ The Pott-Broche process for extracting coal with solvents at elevated temperatures yields an extract containing only 0.05 percent ash. Distillation of the solvent and certain of the oils from the extract gives a residue that can be carbonized to produce a low-ash electrode carbon.94/ Information on the organization of German fuel research and recent developments were obtained at six different research laboratories.95/

Underground Gasification

The underground gasification of coal is a process of exploitation of coal deposits through partial combustion by blasting with air, oxygen, steam, or other fluids and recovering fuel in gaseous form. Thus, the mechanical breaking down of the coal and its transportation to the surface are avoided. The advantages of such a process include the following: Possible utilization of coal beds too thin for economical mining; recovery of the fuel components in a form easily transported and efficiently utilized; avoidance of much difficult and dangerous labor; reduction of the man-hours required for production of a given quantity of fuel; and reduction of the cost of developing and operating a mine, especially where mining operations could be difficult.

The Bureau of Mines is attempting to determine the technical and economic factors involved in gasifying coal in place. Information is being obtained on: The thermodynamics and kinetics of the underground gasification reactions, necessary to determine the size of the installation required and the contact time required; the underground action of heat on overlying strata and underground heat losses; and the action of various gas making fluids and the quality and yield of products.

A laboratory-scale retort was built to simulate as nearly as possible some of the conditions encountered in actual underground gasification. The retort contained a bed of fine coal, about 14 by 7 feet horizontal dimensions; 1 foot 3 inches thick, and having an approximate capacity of 5,200 pounds of coal, enclosed in fire brick, well-insulated and the whole contained in a steel jacket open at the top. Twenty-four refractory tubes were installed at the bottom of the retort at various spots for gas sampling and measuring pressures and temperatures. Two rotary, lobe-type, blowers were installed, one for blast air, the other for removal of the product gas.

Seven experiments on this underground gasification retort have been conducted thus far, with varying conditions, such as length and type of channel, volume of air blown, and use of steam and regenerators. The regenerators were installed at the inlet and outlet of the channel after the second experiment.

Experiments were conducted with air flow through three loops of a "W"-shaped channel, and also other experiments with a single-loop "U"-shaped channel.

93/ Reed, Frank H., Some Observations on Coking Practice in Germany. Part I. Metallurgical Coke, Part II. Slanting-Type Didier Coke Ovens, Stadtische Werke Karlsruhe: Bureau of Mines Inf. Circ. 7462, 1948, 74 pp.

94/ Lowry, H. H., and Rose, H. J., Pott-Broche Coal-Extraction Process and Plant of Ruhrol G.m.b.H., Bottrop-Welheim, Germany: Bureau of Mines Inf. Circ. 7420, 1947, 12 pp.

95/ Lowry, H. H., and Rose, H. J., Some Observations on German Coal Research and Developments: Bureau of Mines Inf. Circ. 7422, 1947, 27 pp.

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Typical data are given in table 17. Figures 30, 31, and 32 show the retort, roof, and residue after this same run.

TABLE 17. - Underground gasification retort run

Time from start to midpoint of cycle:	86.8 hr.	91.3 hr.	95.8 hr.	101.8 hr.	106.3 hr.	110.8 hr.	115.3 hr.	119.8 hr.	121.3 hr.	Average[1]	Calculated air-free
Gas analysis, percent:											
CO_2	11.5	10.5	9.2	9.0	8.8	8.6	8.3	8.9	8.6	8.8	8.9
Ill.	.6	.4	.5	.2	.4	.2	.2	.4	.0	.3	.3
O_2	.0	.2	.0	.0	.7	.0	.3	.4	.0	.2	-
CO	13.6	15.1	18.0	18.5	19.9	19.1	21.1	19.7	21.3	19.7	19.9
H_2	5.8	5.1	4.2	5.7	4.4	3.1	4.2	5.2	3.4	4.3	4.3
CH_4	.9	.9	1.5	.6	.7	2.4	.7	.5	.9	1.0	1.0
N_2	68.6	67.8	66.6	66.0	65.1	66.6	65.2	64.9	65.8	65.7	65.6
B.t.u./c.f. 60-30, dry	83.8	82.4	96.9	88.3	93.6	100.5	92.8	93.6	88.9	93.7	94.3

Average air flow[1]	2,420 c.f.h.
Average gas make flow[1]	2,560 c.f.h.
Cold-gas efficiency[1]	55 percent
Retort charge -	5,180 lb.

Ultimate coal analysis as received:	Percent	
Hydrogen	4.6	
Carbon	75.9	
Nitrogen	1.2	Moisture (as-received)
Oxygen	6.1	2.1
Sulfur	.9	
Ash	11.3	
B.t.u.	13,220	

[1] Average of last 7 analyses.

The laboratory experiments, while not conclusive, have demonstrated some interesting phenomena. Among these are:

A. The gas-making reaction begins in a short distance of blast travel (about 5 percent). The complete gas-making reaction apparently can be attained within the 75 percent of blast travel in the experimental retort.

B. The exploitation of a large area from an initial "U"-shaped passage may be very difficult. The tests indicated that a straight-line passage may be desirable.

C. Unidirectional blast flow is corollary to a straight-line passage. The advantages expected from unidirectional flow are: Simplified operation; less time required for warm-up; less capital cost in construction of hot-gas outlets; consistent product gas quality.

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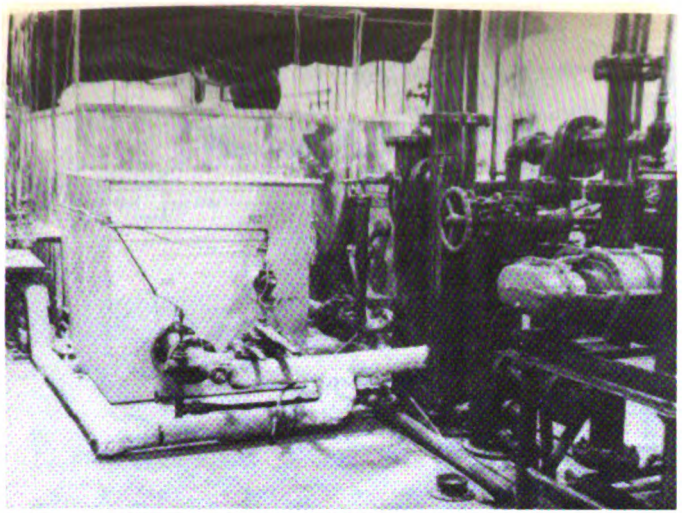

Figure 30. - Experimental underground gasification retort.

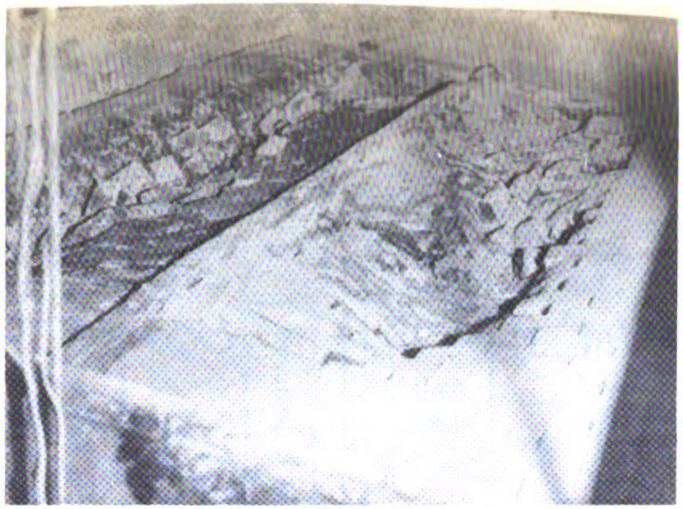

Figure 31. - Underground gasification retort; view of roof after run.

Figure 32. - Underground gasification retort; residu after run.

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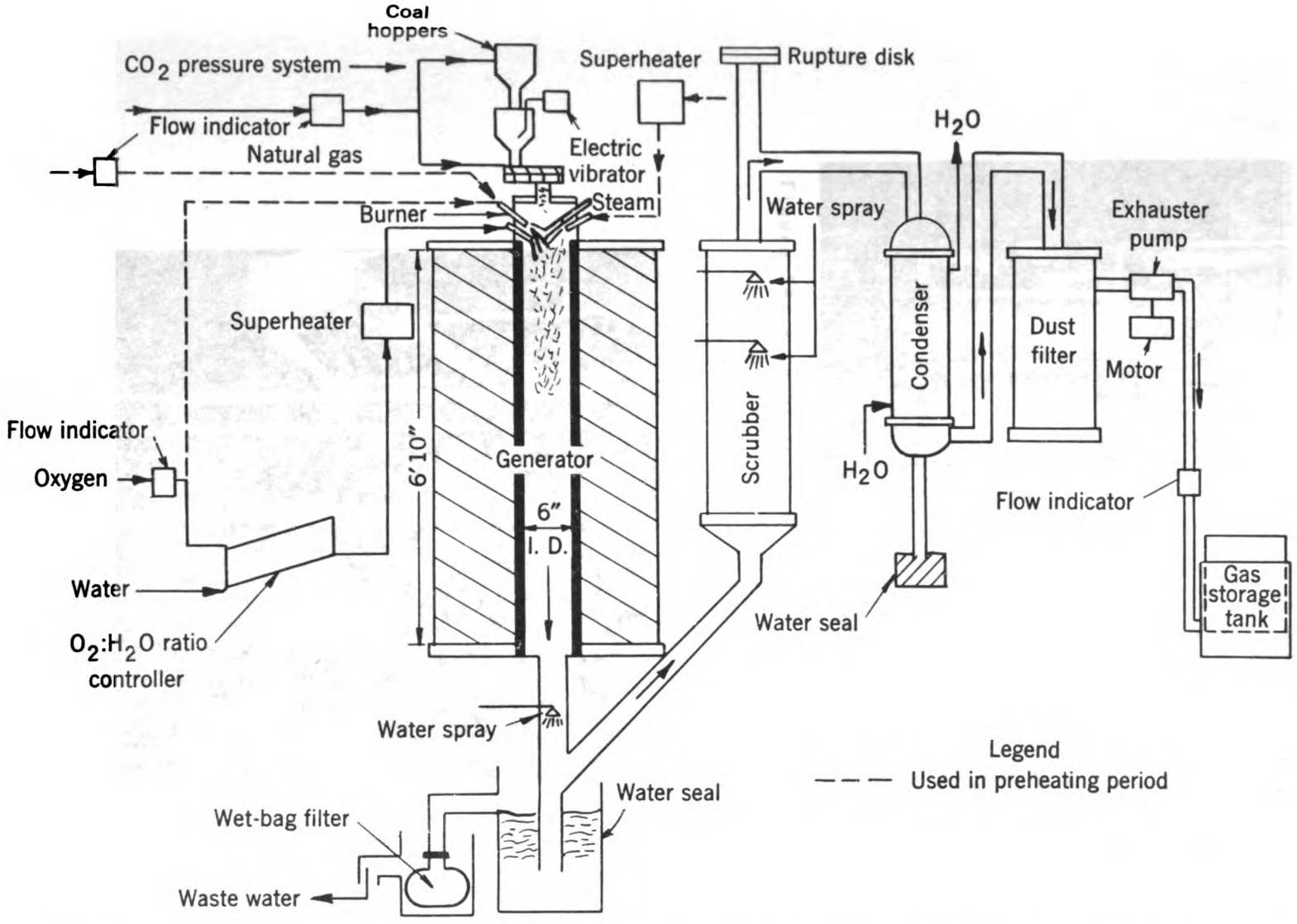

Figure 33. - Laboratory-scale apparatus for the gasification of pulverized fuel by entrainment in oxygen and steam. (Modified generator construction with straight tube arrangement; outlet at bottom; wet handling of products).

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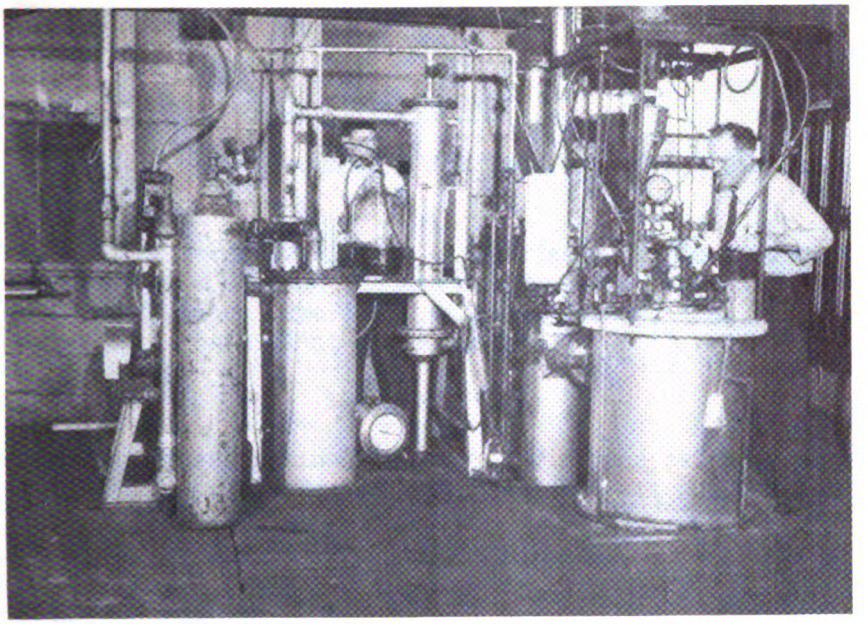

Figure 34. - Laboratory-scale gasification unit by entrainment of pulverized fuel in oxygen, showing accessory equipment.

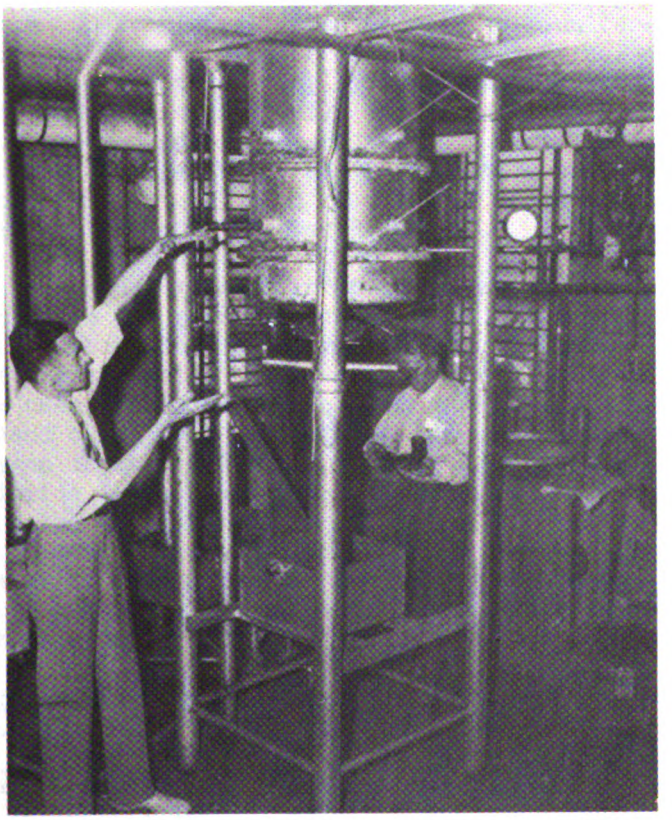

Figure 35. - Laboratory-scale gas generator; lower half.

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Field-Scale Underground Gasification Experiments

The first field-scale underground gasification experiment was conducted at Gorgas, Ala., in 1947.96/

Preparations for the second field-scale experiment are in progress. In June 1948 the Federal Bureau of Mines and the Alabama Power Co. agreed to carry out the second underground gasification experiment, also at Gorgas, Ala., to obtain comprehensive data upon which to base plant-scale operations.

LIQUEFACTION

A report covering Bureau of Mines research during the calendar year 1947 on the production of synthetic liquid fuels from both coal and oil shale was issued.97/

Production of Synthesis Gas

Laboratory-Scale Experimentation

A laboratory-scale pilot unit was designed and a method developed for the gasification of 10 to 30 pounds of pulverized bituminous coal per hour by entrainment in oxygen and steam at generator temperatures ranging from 1,800° to 2,400° F.

In the first series of runs, a noncoking bituminous coal, pulverized so that 72 percent passed through a 200-mesh screen, was charged at a uniform rate into the top of an 82-inch-long vertical refractory tube of 6 inches internal diameter. Engulfed in highly turbulent currents created by impinging oxygen and steam jets, the coal particles were gasified in entrainment, while the residual dust and fly ash were carried downward by the product gases, toward the outlet at the bottom. A self-explanatory flow diagram of the generator and purification train with wet handling of the products is shown in figure 33, and pictures of various parts of the unit and of the instrument board are shown in figures 34 and 35.

A series of runs made under widely different operating conditions proved that the quality of the synthesis gas made (percent combustible constituents, percent carbon dioxide content and carbon monoxide : hydrogen ratio) can be controlled by the proper choice of operating variables. However, the heat losses in internally heated generators of the size used are so excessive that considerably higher oxygen input was required per thousand cubic feet of synthesis gas made than for large plant-size units. The higher oxygen input resulted in a high ratio of carbon monoxide to hydrogen and much carbon dioxide in the make gas. Since an enormous amount of insulation would be needed to make the heat losses per cubic foot of generator volume equivalent to that in large-scale units, balancing of the heat losses by external heating of the generator chamber appears to be the logical way to approach operating conditions on large scale, which would allow the closest translation of the operating results for the designing of plant-size units.

Typical operating results from a 10-hour run, using the wet purification system are given in table 18.

96/ Fies, Milton H., and Schroeder, W. C., Underground Gasification: Mech. Eng., vol. 70, No. 2, February 1948, pp. 127-135.

97/ Report of the Secretary of the Interior on the Synthetic Liquid Fuels Act from January 1, 1947 to December 31, 1947 (to the 80th Cong.).

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TABLE 18. - Operating results - run 13

Item		Period 1	Period 9	Period 10	Period 11	Total or weighted average of periods 1, 9, 10, 11
1	Duration of periods, hr.	0.73	1.00	1.00	1.58	4.31
2	Rate of coal feed, lb./hr.[1]	9.79	9.79	9.79	9.79	9.79
3	Oxygen input, cu.ft./hr.[2]	133	122	134	136	132
4	Total steam input, lb./hr.[3]	2.55	2.21	2.61	3.53	2.84
5	Mol or volume ratio of oxygen to total steam	2.48	2.63	2.44	1.83	2.21
6	Steam input per lb. of coal, lb.	0.261	0.226	0.267	0.361	0.290
7	Output of gas, cu.ft./hr.[2]	336	216	281	283	276
8	Cu. ft. oxygen input per MCF of gas	396	565	477	481	478
9	Coal feed in lb. per MCF of gas made[2]	29.1	45.3	34.8	34.6	35.5
10	Combustible residue, lb./hr.[4]					1.44
11	Percent carbon gasified in fuel charged (gasification efficiency)					78.5
12	Thermal efficiency (percent ratio of B.t.u. in gas to B.t.u. in coal)					57.4
13	Coal feed, lb. per MCF of CO + H_2 made[1]	36.1	71.7	57.0	51.5	52.4
14	Cu. ft. oxygen input per MCF of CO + H_2 made	491	891	784	716	706
15	Lb. steam input per MCF of CO + H_2 made	9.41	16.13	15.26	18.58	15.19
16	Generator wall temperature, 8 inches from top, °F.	2,148	2,214	2,295	2,333	2,265
17	Generator wall temperature, 28 inches from top, °F.	1,897	1,684	1,761	1,823	1,789
18	Generator wall temperature, 59 inches from top, at bottom of silicon carbide tube, °F.	1,398	1,043	1,055	1,070	1,116
19	Generator wall temperature, 71 inches from top, °F. (slagging zone)	1,303	1,001	1,044	1,076	1,090
20	Gas analyses, percent:[5]					
	CO_2	14.0	29.9	32.1	26.9	26.0
	O_2	1.4	1.8	1.0	1.5	1.4
	Ill. (C_2H_4)	.6	.5	.3	.3	.4
	H_2	44.0	26.6	25.8	27.6	30.4
	CO	36.7	36.6	35.2	39.6	37.4
	CH_4	.3	1.4	2.6	2.8	2.0
	N_2	3.0	3.2	3.0	1.3	2.4
	Calculated B.t.u. (60, 30, dry, gross)	274	227	229	251	246

1/ On as-charged basis.
2/ Cu. ft. at 60° F., 30 in. Hg, dry, is shown in all cases.
3/ Includes steam from moisture in the coal charged, from water formed by the combination of oxygen with equivalent hydrogen in the coal, and from water vapors carried by the injected oxygen.
4/ On moisture- and ash-free basis.
5/ Corrected for CO_2 introduced for purging purposes.

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The decomposition of methane in a porcelain tube at temperatures between 1,007° and 1,075° was studied.98/ The following observations were made:

(1) Within this range the first-order reaction constants increased with increasing decomposition.

(2) There was a catalytic effect of acetylene, probably homogeneous, which accounts for (1), since the percentage of acetylene increased with increasing percentage of decomposition.

(3) There was probably no effect of ethylene on the decomposition of methane.

(4) There was a large catalytic effect of surface in the early stages of the reaction which disappeared by the time 30 percent of the methane was decomposed.

(5) No induction period was found.

(6) In the early stages of the decomposition, 50 percent nitrogen or steam in the entering gas resulted in about the same percentage of decomposition of the methane for equal contact time.

The production of alcohols is possible either as a primary objective or as an unavoidable by-product in the production of oil and gasoline by the Fischer-Tropsch process.99/ Alcohols could serve as part of the motor fuel, and some of the higher molecular weight alcohols could command a relatively higher price and thus absorb part of the refining costs.

Purification of Synthesis Gas

For the production of synthetic liquid fuels it is proposed to produce synthesis gas directly from pulverized coal rather than from coke. For this reason purification problems are involved which are extremely difficult and unique so far as American gas-production practice is involved. The German100/ synthetic-fuels industry avoided the production of synthesis gas from pulverized coal, partly because of anticipated purification difficulties, especially in connection with dust removal.

Impurities that may be present in gas made from pulverized coal and that must be removed include: Tar, dust, ammonia, hydrogen cyanide, napthalene, gum-forming hydrocarbons, nitric oxide, hydrogen sulfide, and various organic sulfur compounds. Since removal of these impurities must be virtually complete, there are not only difficult purification problems to solve but also new requirements for sensitivity and precision in analytical methods used to determine the performance of purification processes.

Much progress has been made in the development of analytical methods. Previous methods have been improved to give greater precision and reduce the time required for obtaining analytical results.

98/ Gordon, Alvin S., Pyrolysis of Methane Flowing Through a Porcelain Tube in the Region 1,000°: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 395-401.

99/ Schroeder, W. C., Fischer-Tropsch Alcohol: Chem. Eng. Prog., vol. 44, No. 1, January 1948, pp. 15-17.

100/ Sands, A. E., Wainwright, H. W., and Schmidt, L. D., The Purification of Synthesis Gas Produced from Pulverized Coal: Ind. Eng. Chem., vol. 40, April 1948, p. 607.

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Pilot-Plant-Scale Experimentation

Construction of the synthesis-gas pilot plant has progressed to the point where trial runs have been made in a Royster pebble stove. The generator has been completed and heated to about 2,000° F. Equipment for the automatic control of the process is being received and erected.

In addition to the work of erecting the pilot plant and making test runs on the stoves, research has been carried on with various refractory materials to determine their ability to withstand high temperatures (3,000° to 4,000° F.) and severe thermal shock. As a result of this work, several materials which appear to be satisfactory for pebble material and stove linings have been found.

The attached flow sheets (figs. 36 and 37) show the process; figures 38 and 39 are cross sections of the stoves and generator; and figure 40 is a close-up of the Royster Stoves and connections to the generator.

Demonstration-Plant Construction

The design of the 80- to 100-barrel-per-day Gas-Synthesis Demonstration Plant is well underway at Louisiana, Mo. Construction is in the grading and excavation stage. The plant will include pulverized-coal gasification with steam and oxygen, gas-purification, gas-synthesis, and product-distillation sections.

A 1-ton-per-hour capacity, 98 percent purity, Linde-Frankl oxygen plant was shipped from Hoechst, Germany, to Louisiana and was erected to provide the oxygen requirements for the gasification of pulverized coal.

Use of Oxygen in the Production of Synthesis Gas

The use of oxygen in the production of hydrogen or synthesis gas was reviewed.101/ Processes for large-scale production of hydrogen and synthesis gas are basically identical. A plant producing 25,000 barrels of primary liquid fuel per day requires 700 to 800 million cubic feet of synthesis gas per day. Low-cost synthesis gas requires the use of lower-priced generator fuels, which can best be gasified in processes using oxygen. It was concluded that the American requirements may best be satisfied by gasifying pulverized fuel in suspension. This will permit the use of higher rank caking or noncaking coals, as well as lower rank subbituminous coals or lignite.

Synthesis of Liquid Fuels from Hydrogen and Carbon Monoxide

Laboratory-Scale Experimentation

Attention was called to the apparent impossibility of accounting for the isomeric composition of Fischer-Tropsch hydrocarbons on the basis of the carbidic carbon-methylene polymerization hypothesis.102/ The hydrocarbon product, boiling in the gasoline range, has been found to contain 10 to 15 percent of singly branched hydrocarbons

101/ Newman, L. L., Oxygen in the Production of Hydrogen or Synthesis Gas: Ind. Eng. Chem., vol. 40, April 1948, pp. 559-582.

102/ Storch, H. H., Review of Development of Processes for Synthesis of Liquid by Hydrogenation of Carbon Monoxide: Chem. Eng. Progress, vol. 44, 1948, No. 6, pp. 469-480.

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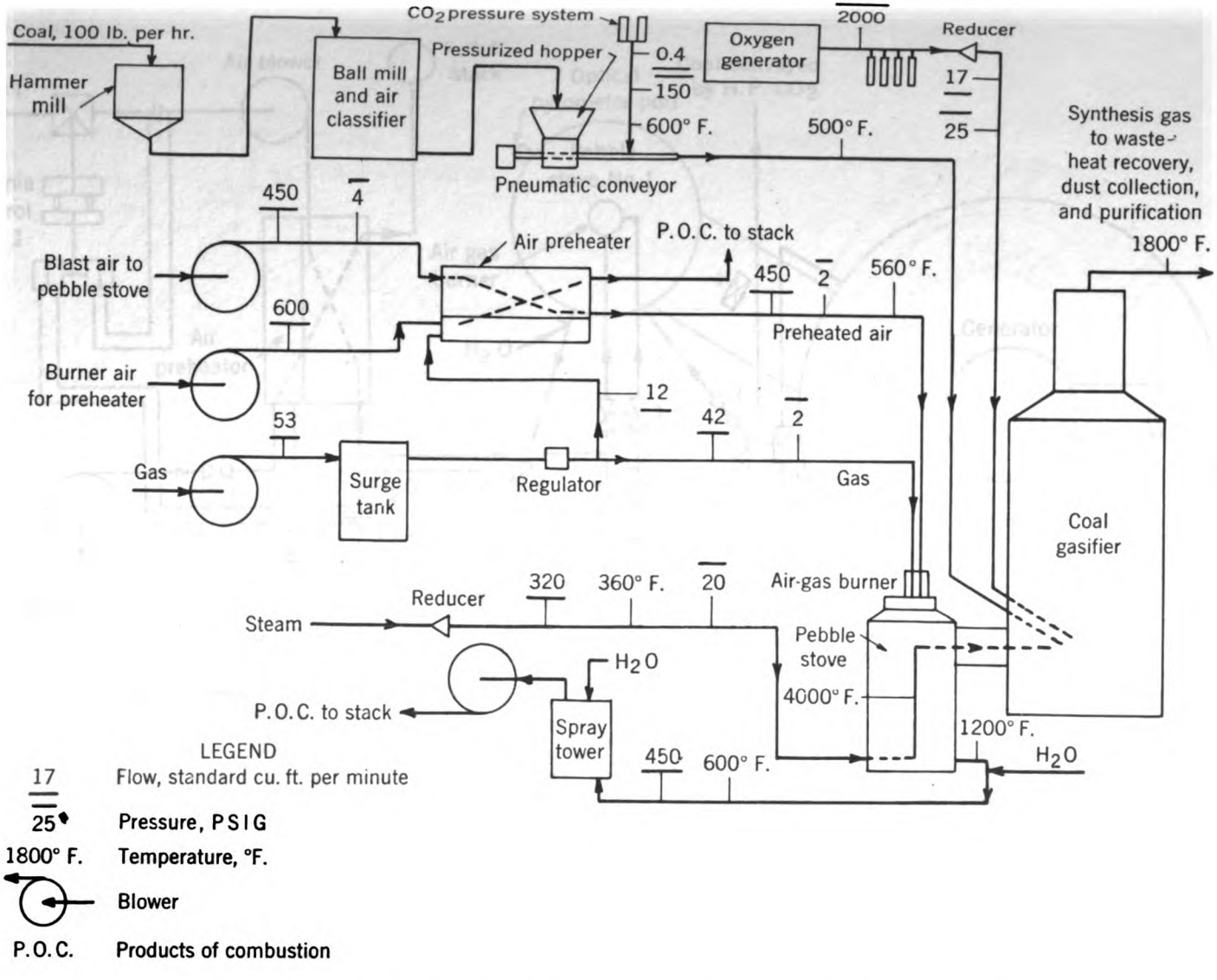

Figure 36. - Flow sheet for plant gasifying pulverized coal.

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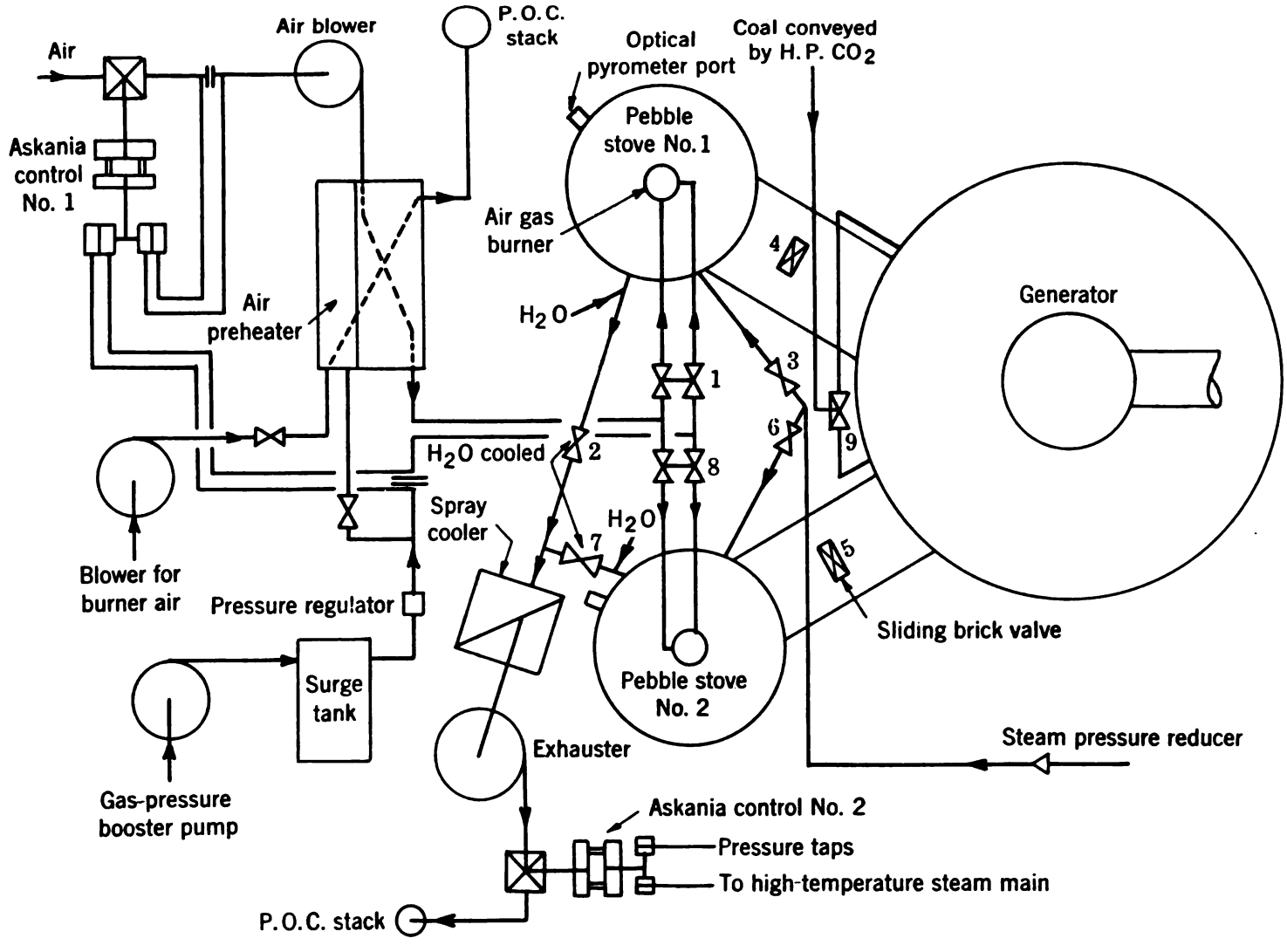

Figure 37. - Valve and instrumentation diagram.

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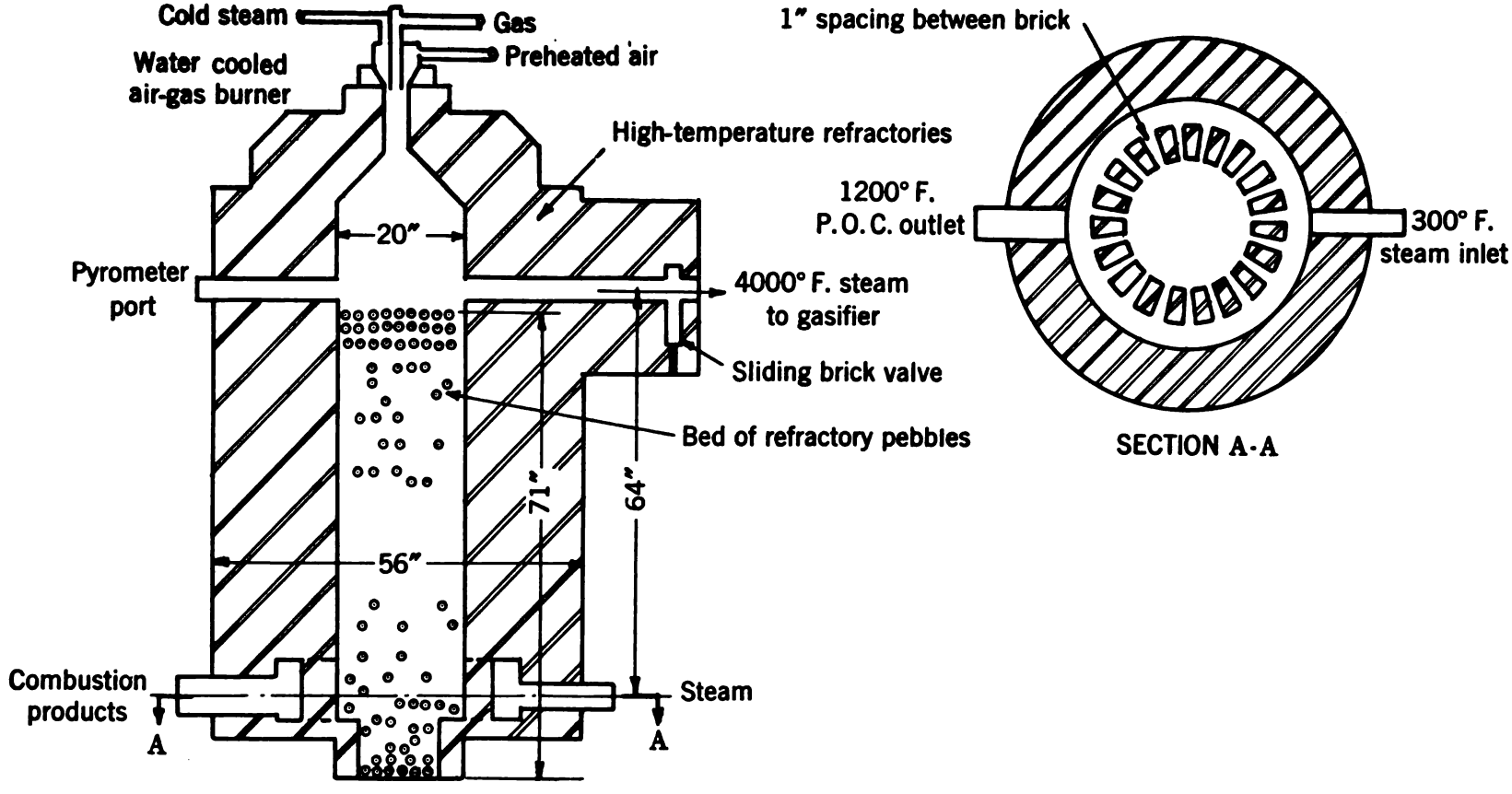

Figure 38. - Royster pebble stove to superheat reaction steam in pulverized-coal-gasification plant.

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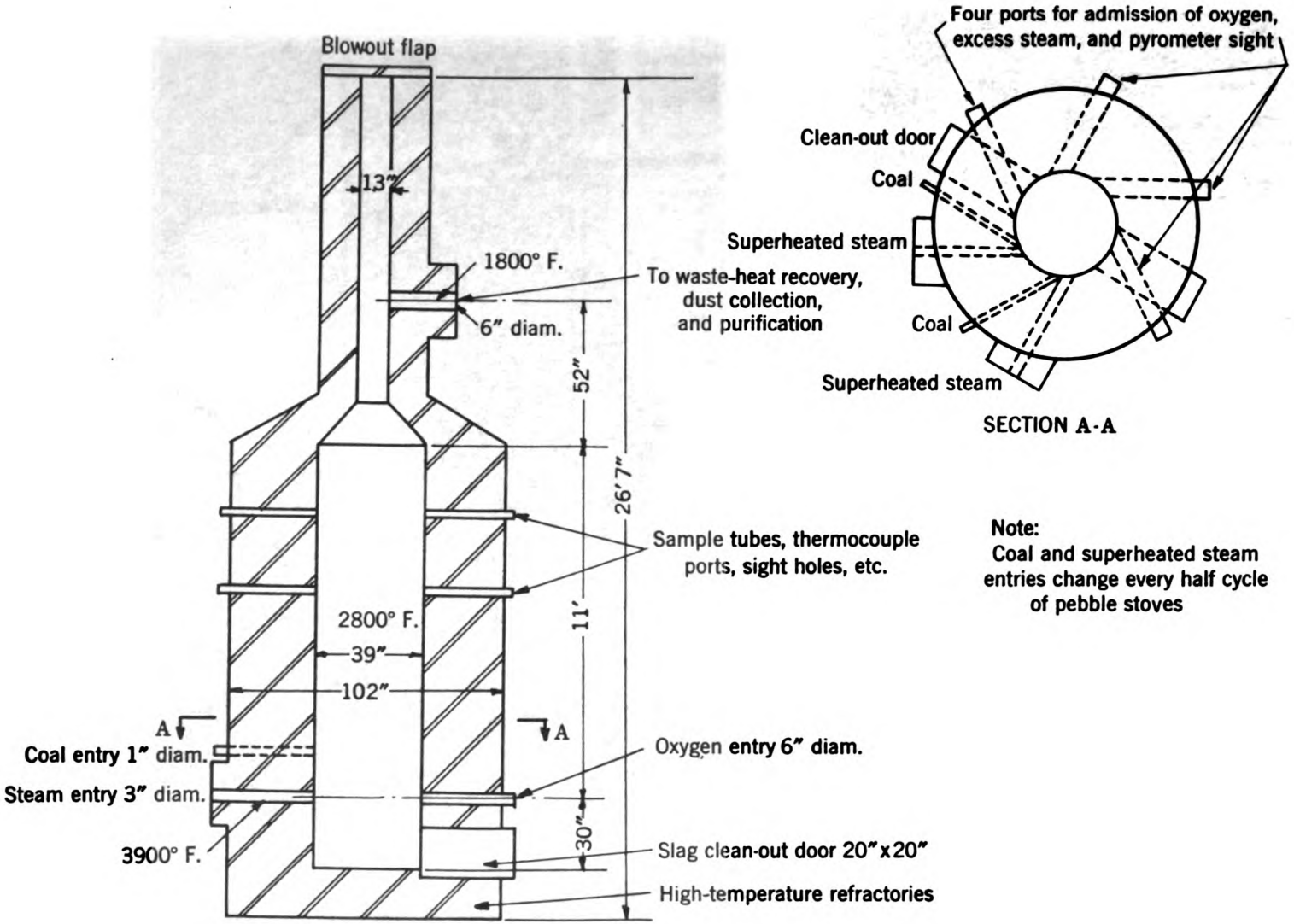

Figure 39. - Coal gasifier for coal-gasification plant.

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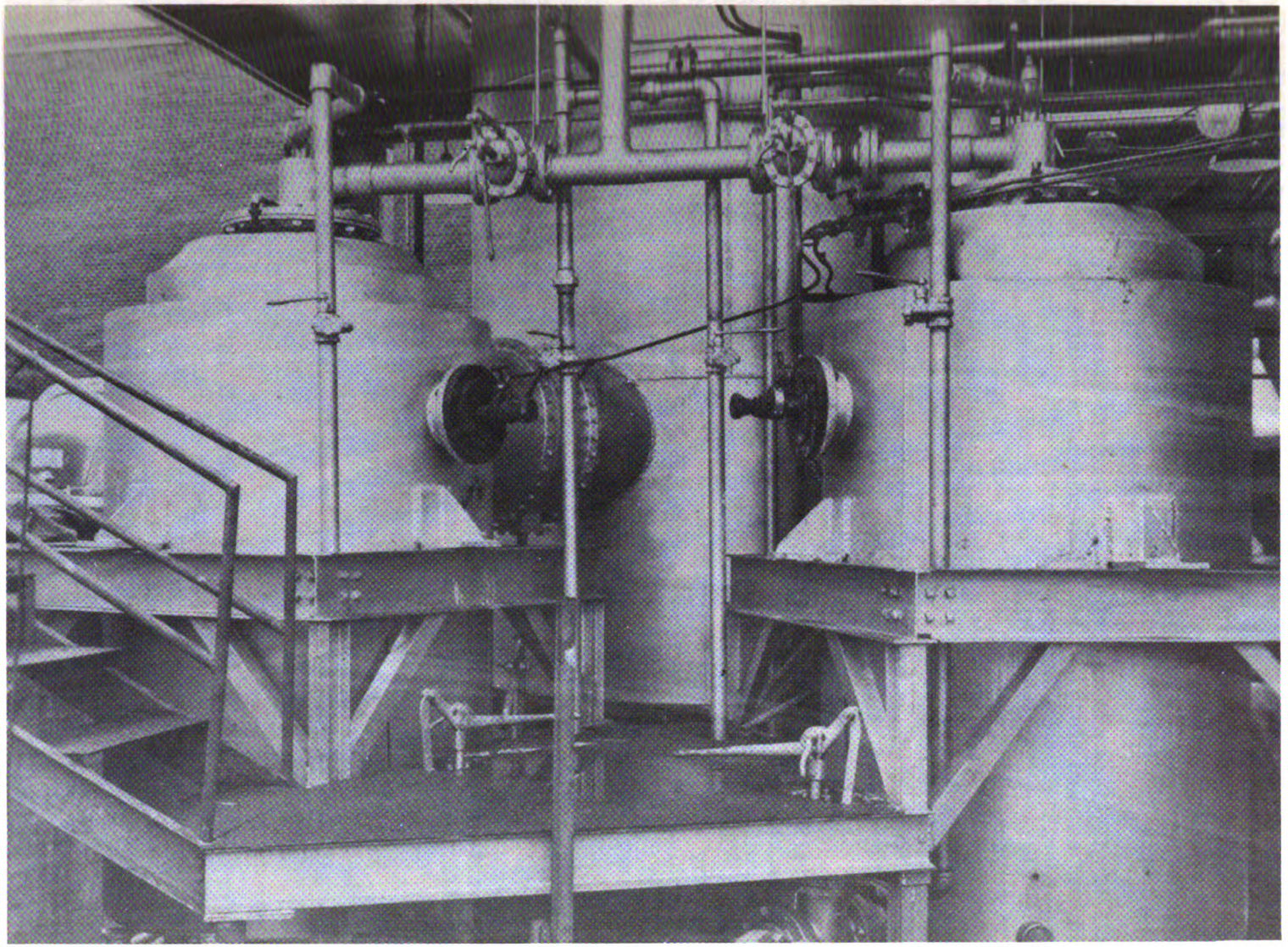

Figure 40. - Close-up view of Royster stoves and connections to the generator.

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with a methyl group in the 2 or 3 position. No appreciable amounts of multiple-branched hydrocarbons or of branches containing more than one carbon atom have been found. If the mechanism of the synthesis involves carbidic carbon and methylene group polymerization, branching would occur whenever a carbidic carbon is added to the chain of methylene groups. According to this mechanism, there is no obvious limitation to the number of branches per molecule or to the length of a branch.

Another fact that is extremely difficult to explain on the basis of the carbidic carbon-methylene polymerization mechanism is that alcohols are the precursors of olefins in the "synol" process. The latter is identical with the Fischer-Tropsch synthesis on iron catalysts, except that a much higher degree of recycling of end gases with removal of carbon dioxide in each cycle is employed. The product of the synol process contains 50 to 60 percent of chiefly normal alcohols, as compared with 20 to 30 percent in the product of the Fischer-Tropsch process. Because the essential difference between the synol and the Fischer-Tropsch synthesis is the much shorter retention time of the products in the former process, it is probable that normal alcohols are early products and that the olefins result from dehydration of these alcohols.

In an attempt to explain the facts concerning the composition of Fischer-Tropsch products, it was suggested that a reaction similar to the "OXO" reaction may occur on the surface of catalysts during the synthesis of hydrocarbons and alcohols by the Fischer-Tropsch and synol processes. The essential features of the "OXO" process have been reviewed and a mechanism for the reaction proposed.[103/] This process consists in reacting olefins with carbon monoxide and hydrogen to produce aldehydes and subsequent reduction of the latter with hydrogen to alcohols. The basic reaction was discovered by the Ruhrchemie, and a large-scale continuous process resulted from cooperative efforts of Ruhrchemie and I. G. Farbenindustrie. A slurry of liquid olefin plus 3 to 5 percent reduced Fischer-Tropsch cobalt-thoria-magnesia-kieselguhr catalyst is pumped along with 1 H_2 + 1CO gas (about 0.2 cubic meter per liter of olefins) through a preheater (150-160° C.) into two reactors at 200 atmospheres pressure. The second reactor is in series with the first, and an equal amount of gas (0.2 cubic meter per liter of olefin) is pumped into the second reactor. The excess H_2 + CO in both reactors serves to agitate the reaction mixture. Ethylene and propylene react readily when used in solution in a liquid medium. The contact time is about 20 minutes. Most of the catalyst is filtered off and recycled. The conversion is 70 percent in the first reactor and 30 percent in the second. The product consists of 80 percent aldehydes (about one-fourth of this is polymerized aldehyde) and 20 percent alcohols. It is not practical to isolate aldehydes from the first state and it is considered preferable to dehydrogenate the corresponding alcohols from the second stage.

Because hydrogenation of the aldehydes is retarded by carbon monoxide, the first-stage product must be let down to atmospheric pressure. The second stage is operated with hydrogen at 170°-195° C. and at 200 atmospheres pressure. Fischer-Tropsch cobalt catalyst (from the first stage) or copper chromite may be used in the second stage. If the former is used, some carbon monoxide is formed by decomposition of cobalt carbonyl, and the exit gas is passed over an iron catalyst at 250° C. to convert the carbon monoxide to methane, whose concentration up to about 10 percent is of only slight importance. The second stage is otherwise identical with the

103/ Wender, I., and Orchin, M., Critical Review of Chemistry of OXO Synthesis for Production of Alcohols from Olefins, Carbon Monoxide and Hydrogen, with Discussion of Reaction Mechanism for OXO and Related Syntheses: Bureau of Mines Rept. of Investigations 4270, 1948, 26 pp.

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first. The first stage is not affected by sulfur compounds, but the second is very sensitive; and, if sulfur compounds are present, sulfide catalysts (such as mixture of nickel and tungsten sulfides) must be used.

The reaction in the first stage probably is a homogeneous catalytic reaction with either cobalt carbonyl or cobalt hydrocarbonyl as the catalyst. The insensitivity to sulfur poisoning and the fact that any finely divided reactive cobalt compound may be used support this assumption.

The aldehydes and alcohols produced are a mixture of normal and isocompounds. This is due not only to orientation of the hydrogen with respect to the carbon-carbon monoxide bonds in the initial reaction complex, but also to isomerization of the olefin under the process conditions. It may be significant that nickel carbonyl does not readily shift the olefin double bond under the OXO-process conditions, and nickel compounds are very poor catalysts for the process. From isooctene, 32 percent of n-nonyl alcohol and from propylene 50 percent of n-butyl alcohol are obtained, the remainder of the products being iso-alcohols. In general, using x-olefins as raw material one obtains about 60 percent of isoalcohols. The synthesis will not occur unless a labile hydrogen atom is available in the olefin reactant; with diolefins, the reaction takes place at only one double bond.

This suggestion[104] leads to the assumptions that the chief reactions occurring on a Fischer-Tropsch catalyst are:

(1) Formation of methylene groups by reduction of chemisorbed carbon monoxide.

(2) Formation of ethanol by addition of carbon monoxide and hydrogen to a methylene group.

(3) Dehydration of ethanol to ethylene.

(4) Steps similar to 2 and 3, starting with ethylene, propylene, etc., for formation of higher alcohols and olefins.

In this series of reactions, alcohols are the precursors of the olefins; not more than one branch per molecule can be formed; and, because of steric factors, formation of branches containing more than one carbon atom is highly improbable.

From a bed of cobalt-thoria-kieselguhr catalyst 36 inches deep contained in a 1/2-inch-diameter laboratory converter,[105] samples were removed at points 2-1/2 inches apart. Five percent argon was added to the original synthesis gas as an inert reference component. The rate of removal of a sample was slow enough so as not to cause any appreciable perturbation in the total flow of synthesis gas through the reactor.

The synthesis rate was high in the initial part of the bed, and lower and fairly constant throughout most of the catalyst bed, until the reactants were virtually completely consumed. Over the range of constant synthesis rate, the gas composition

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104/ See footnote 103, p. 77.

105/ Anderson, R. B., Krieg, A., Seligman, B., and O'Neill, W. E., Studies of the Fischer-Tropsch Synthesis. Part I. Tests with Cobalt Catalysts at Atmospheric Pressure: Ind. Eng. Chem., vol. 39, 1947, pp. 1548-1554.

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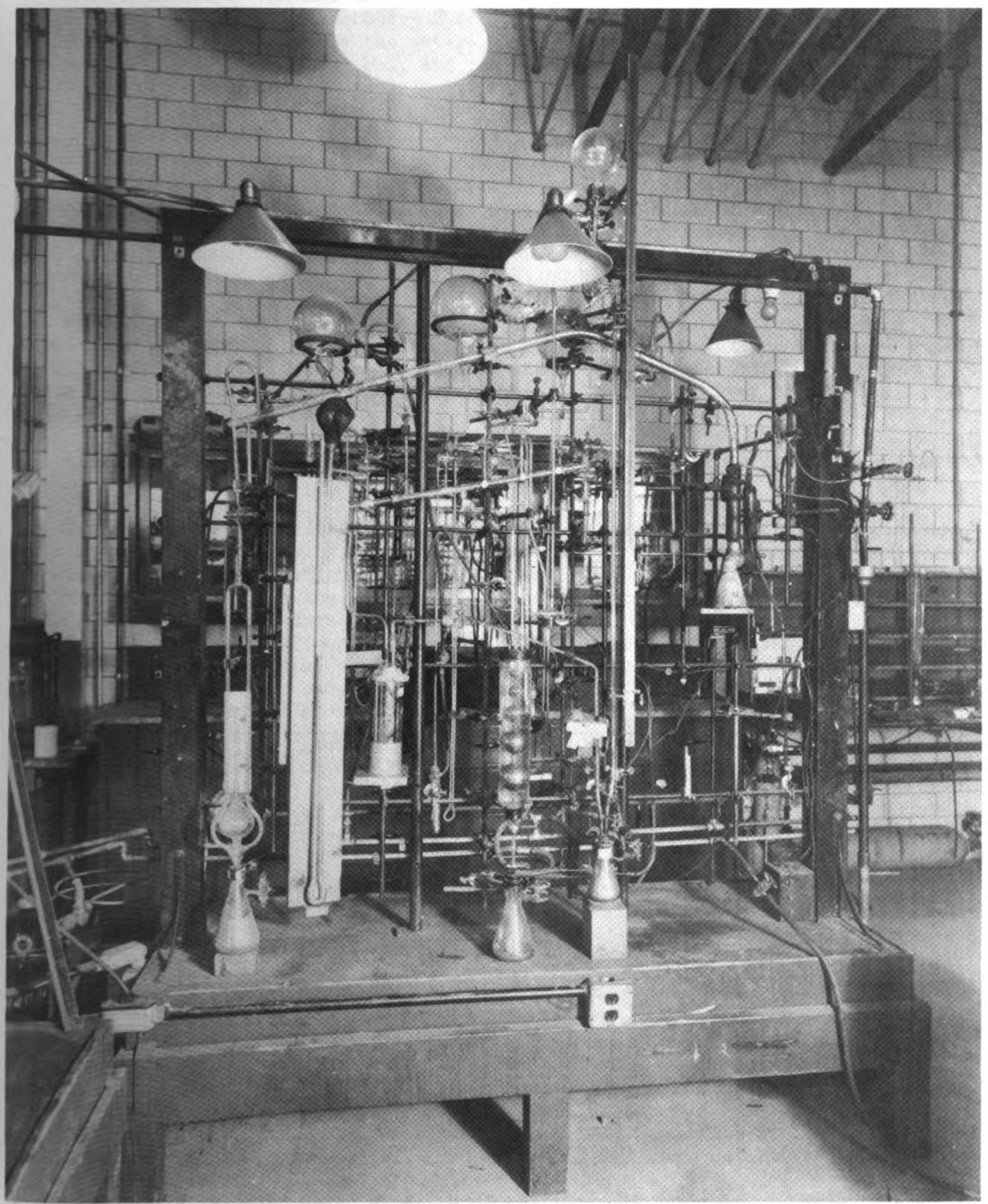

Figure 41. - Apparatus for measuring surface areas of catalysts.

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varied considerably. Methane and carbon dioxide were formed by primary reactions; methane also was formed by secondary hydrocracking of higher molecular weight hydrocarbons, and carbon dioxide by the water-gas shift reaction. These reactions occurred throughout the catalyst bed, and their extent depended upon the composition of the gas in contact with the catalyst.

The X-ray diffraction patterns of cobalt carbide[106] and of the three iron carbides[107] have been accurately determined. This information combined with the magneto-chemical constants[108] and earlier determinations of such patterns and constants for the iron oxide phases[109] have provided the essential elements for analysis of Fischer-Tropsch catalysts by physical methods. An interesting byproduct of the work on the physical properties of the various iron oxides was the determination of the nature of iron compounds in red and yellow sandstone.[110]

Measurements,[111, 112] of pore volumes, and activated adsorption of carbon monoxide are being made on all catalysts tested. For iron catalysts which are fused or highly sintered, the desirability of complete reduction with hydrogen prior to use in the synthesis is best explained by the creation of a system of pores and fissures by the reduction.

A photograph of apparatus used for surface area measurements is shown in figure 41.

To insure reproducibility of pilot plant operations, all catalyst preparations are tested for their activity, and some indications of durability are obtained during several weeks of operations in catalyst testing units. A large proportion of catalyst testing involves the search for cheaper iron catalysts of suitable mechanical form, activity, and durability. The most promising catalyst for the internally cooled process consists of magnetite-ore fines which have been impregnated with alkali and copper solutions, extruded, dried, and sintered. For the slurry process, special precipitated-iron catalysts and those prepared by ignition of ferric nitrate-starch mixtures have been most promising.

106/ Hofer, L. J. E., and Peebles, W. C., X-ray Diffraction Studies of the Action of Carbon Monoxide on Cobalt-Thoria-Kieselguhr Catalysts: Jour. Am. Chem. Soc., vol. 69, 1947, pp. 2497-2500.

107/ Weller, S., Kinetics of Carbiding and Hydrocarbon Synthesis with Cobalt Fischer-Tropsch Catalysts: Jour. Am. Chem. Soc., vol. 69, 1947, pp. 2432-2436.

108/ Weller, S., Hofer, L. J. E., and Anderson, R. B., The Role of Bulk Cobalt Carbide in the Fischer-Tropsch Synthesis: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 799-801.

109/ Storch, H. H., Hawk, C. O., Golumbic, N. R., Hofer, L. J. E., and Anderson, R. B., Synthetic Liquid Fuel Processes. Hydrogenation of Carbon Monoxide, Part I. Review of Literature and Data on Effect of Preparation, Reduction, and Induction Procedures on Catalyst Activity; and on Correlation of Activity with Physical Properties of Catalysts: Bureau of Mines Tech. Paper 709, 1948, 213 pp.

110/ Hofer, L. J. E., and Weller, S., The Nature of the Iron Compounds in Red and Yellow Sandstone: Science, vol. 107, 1947, p. 470.

111/ Anderson, R. B., Hall, W. K., Hewlett, H., and Seligman, B., Studies of the Fischer-Tropsch Synthesis II. Properties of Unreduced Catalysts: Jour. Am. Chem. Soc., vol. 69, 1947, pp. 3114-3119.

112/ Anderson, R. B., and Hall, W. K., Modifications of the Brunauer, Emmett, and Teller Equation I: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 1727-1734.

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A sample of Ruhrchemie catalyst 234, containing iron, copper, calcium oxide, potassium oxide, and diatomaceous earth in the proportions by weight of 100 : 2.5 : 10 : 3 : 15 and several batches of Bureau of Mines iron-copper-potassium oxide - 100 : 10 : 0.5, were tested. Both catalysts were prepared by precipitation from aqueous solutions of the nitrates of iron and copper. For these catalysts, reduction with hydrogen was found to be undesirable, compared with an induction with either $2H_2$ + 100 gas at 255° C., or with $1H_2$ + 100 at 230° C., at atmospheric pressure before use in the synthesis at 7 atmospheres pressure. The yield obtained at 230° C. and 7 atmospheres was 125 grams of hydrocarbons from propane to wax, per cubic meter of synthesis gas. Of this yield, about 100 grams per cubic meter were hydrocarbons from pentane to wax. This yield decreased during 12 weeks of operation by about 20 percent.

A photograph of the rebuilt catalyst testing units is shown in figure 42.

A correlation was developed[113] which permits the estimation of heat transfer coefficients if the physical properties of the fluid and the dimensions of the apparatus are known. A maximum heat transfer coefficient was noted with the ratio of particle to tube diameter was about 0.15. The effects of uniformity of packing, shape, surface roughness, and thermal conductivity of the granules were studies. The results showed a negligible effect of surface roughness, and a definite relationship between thermal conductivity and heat transfer rates.

This research[114, 115, 116, 117, 118, 119] was done to make possible more accurate estimates of the energy requirements of the Fischer-Tropsch hot-gas recycle and other processes in which large linear velocities of gases through packed tubes were necessary. A general relationship was developed from experimental data on pressure drop through packed tubes which quantitatively correlates the shape and roughness of the granules and the packing density with the pressure drop. Graphic methods for estimating the percentage of voids from the size and shape of the granules and the dimensions of the vessel were developed.

Work on the liquid-phase catalyst suspension process using a laboratory-size reactor yielded valuable data on the effects of catalyst concentration, gas flow rate, temperature, and pressure. Because these tests indicated a much lower durability of the catalysts than was expected from data in captured German documents, a careful study was made of the effects of the degree of uniformity of the catalyst suspension and of the linear velocity of gas and liquid flows, as well as of particle size of catalyst. Using these data, a pilot plant of 1 to 3 gallons per day capacity has been designed and operated.

113/ Leva, M., Heat Transfer to Gases Through Packed Tubes: Ind. Eng. Chem., vol. 39, 1947, pp. 857-859.

114/ Leva, M., Pressure Drop Through Packed Tubes, Part I. A General Correlation: Chem. Eng. Progress, vol. 43, 1947, pp. 549-554.

115/ Leva, M., and Grummer, M., Pressure Drop Through Packed Tubes, Part II. Effect of Surface Roughness: Chem. Eng. Progress, vol. 43, 1947, pp. 633-638.

116/ Leva, M., and Grummer, M., Pressure Drop Through Packed Tubes, Part III. Prediction of Voids in Packed Tubes: Chem. Eng. Progress, vol. 43, 1947, pp. 713-718.

117/ Brinkley, S. R., Contact Times of Continuous-Flow Reaction Systems with Volume Change: Ind. Eng. Chem., vol. 40, 1948, pp. 303-307.

118/ Leva, M., and Grummer, M., Heat Transfer to Gases Flowing in Turbulent Motion Through Packed Tubes: Ind. Eng. Chem., vol. 40, 1948, pp. 415-419.

119/ Leva, M., Weintraub, M., Grummer, M., and Clark, E. L., Cooling of Gases Through Packed Tubes: Ind. Eng. Chem., vol. 40, 1948, pp. 747-752.

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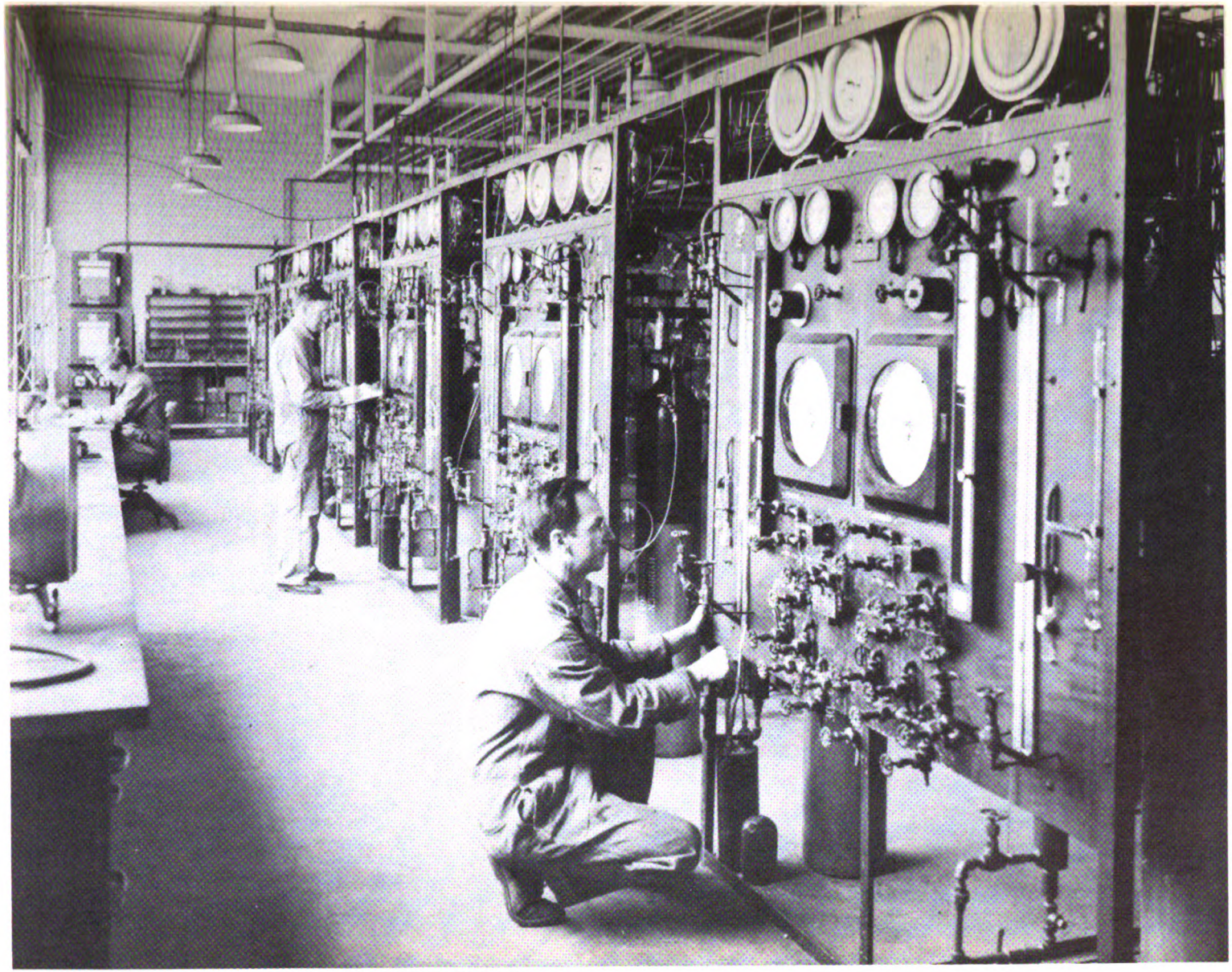

Figure 42. - Catalyst testing units.

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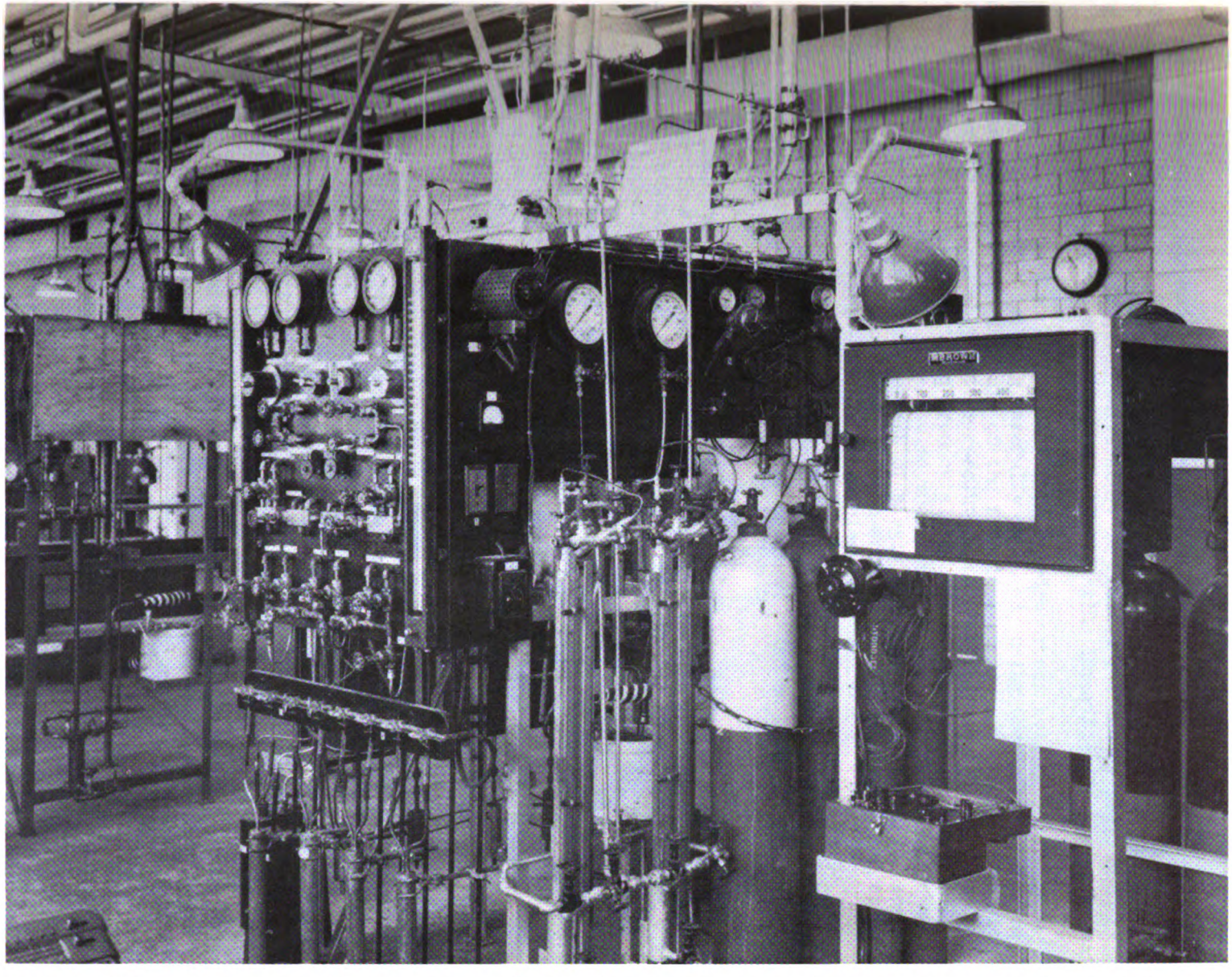

Figure 43. - Equipment for study of effect of reduction conditions on iron-catalyst activity.

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A detailed study was made of the effects of different degrees of reduction of fused synthetic ammonia-type iron catalyst, using the apparatus shown in figure 43. For maximum durability and activity, virtually complete reduction is desirable. The rate of reduction at any given temperature is greatly reduced by small amounts of water vapor and by carbon monoxide and carbon dioxide impurities in the hydrogen.

The isomeric composition of Fischer-Tropsch hydrocarbons boiling in the gasoline range (up to 200° C.) is being carefully measured, using the infrared and the mass spectrometers. Because the bulk of the fractions consists of normal straight-chain hydrocarbons, appreciably better resolution is obtained with the mass spectrometer. Products from cobalt and iron catalysts and from different iron-catalyst processes are being analyzed. The results thus far show that, for both cobalt and iron catalyst products, 10 to 25 percent of singly branched hydrocarbons is present. The branching is usually at the 2- or 3-carbon-atom position. No branch larger than a methyl group and no multiple-branched molecules have been found.

Infrared analyses of fractions of the paraffin-naphthene fractions of light oil from coal hydrogenation have confirmed older analyses based on boiling range, refractive index, etc.

A fairly complete quantitative analysis has been made of the phenol, cresol, and xylenol fractions of tar acids in coal-hydrogenation oils. Starting with a large sample of hexane-soluble oil, the tar acids were extracted with alcoholic caustic. The tar acids were separated after acidification of the extract. After evaporation of the solvent, the crude phenols constituted 9.6 percent of the hexane-soluble oil. 63.5 percent of the crude phenol was distillable below 180° C. at 2.5 mm. of mercury pressure. The distillable tar acids were fractionally distilled and the phenol, cresol, and xylenol fractions separated. The constituents of these fractions were qualitatively identified by preparation of derivatives of known physical properties, and quantitatively determined by infrared spectrometry. Infrared techniques were improved by studies of radiation sources[120] and of calibration methods.[121]

In addition to infrared analysis, another quantitative procedure for separation and determination of individual tar acids is being studied. This procedure involves countercurrent distribution between immiscible solvents. The differences in partition coefficients in the system cyclyhexane - 0.5 m. phosphate aqueous solution of pH 11.08 are large enough to permit such quantitative separations. Standardization tests are being made, and it is expected that this procedure will make it possible to effect separations which cannot be made by any other method.

The isolation and identification of polynuclear hydrocarbons[122] in coal hydrogenation oils is being greatly aided by precise ultraviolet sprctrometric measurements.[123]

120/ Friedel, R. A., and Sharkey, A. G., Jr., Comparison of Glower and Globar Sources for Infrared Spectrometry: Rev. Sci. Instr., vol. 19, 1947, pp. 928-930.

121/ McKinney, D. S., and Friedel, R. A., Calibration Method for Infrared Prism Spectrometers: Jour. Opt. Soc. America, vol. 38, 1948, pp. 222-225.

122/ Woolfolk, E. O., Orchin, M., and Storch, H. H., Note on the Constitution of Heavy Oil from Coal Hydrogenation: Fuel in Sci. & Prac., vol. 26, May-June 1947, p. 78.

123/ Friedel, R. A., Orchin, M., and Reggel, L., Steric Hindrance and Short Wave-Length Bands in the Ultraviolet Spectra of Some Naphthalene and Diphenyl Derivatives: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 199-204.

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Ultraviolet spectrometry has been of indispensable assistance also in the aromatic cyclodehydrogenation studies. These studies[124, 125, 126] were made to assist in identifying polynuclear hydrocarbons present in coal-hydrogenation oils and to provide an understanding of their mode of formation.

An experimental unit for gasifying powdered coal with oxygen and steam has been designed and erected. A general view of the unit is shown in figure 44. The essential components include an oxygen-supply system, a steam superheater, coal-feeding mechanism, reactor, and dust separator. The reactor is of the vortex type and has a design capacity of approximately 100 pounds of coal per hour. Arrangements have been provided to supply up to 2,000 cubic feet of oxygen per hour and to supply 250 pounds of steam per hour, superheated to approximately 1,500° F. The heat loss from the unit is estimated to be less than 5 percent of the heat in the coal feed at the design conditions. Mechanics of starting the unit involved several short trial operations. Recent operations have been free of any major difficulties and it is expected that the utility of the vortex for powdered coal gasification will be determined within the next year.

Process Development - Pilot-Plant Operations

Operation of the internally cooled (by oil circulation) process using a completely flooded bed of granular iron catalyst has been found feasible if the physical structure of the catalyst is such as to avoid disintegration by hydraulic action of the oil. Precipitated and pellated iron catalysts are not sufficiently robust; but the sintered, or fused, iron oxides are satisfactory. Using a doubly promoted (with potassium and aluminum oxides) synthetic ammonia-type catalyst, several runs were made in the pilot plant after moving it from its Pittsburgh location to Bruceton, Pa. These operations varied in duration from several weeks to several months and were planned to ascertain the optimum operating conditions. Although not yet completely determined, these conditions now are reasonably well known, and the present operation will yield durability as well as product quality and product distribution data. A photograph of the plant is shown in figure 45.

The internally cooled process, as now visualized, will operate with largely conductive (by oil circulation) rather than evaporative cooling. For production of maximum amount of Diesel oil, the temperature will be in the range 230°-260° C., the pressure 300 to 450 p.s.i., and the product about 30 percent wax, 35 percent Diesel oil, and 35 percent gasoline. The wax will be subjected to noncatalytic cracking for additional Diesel oil production. For maximum gasoline production, the temperature will be in the range 300°-325° C., pressure 300 to 450 p.s.i., and the product chiefly gasoline with about 15 percent of Diesel oil and 2 to 5 percent of wax. The space-time yield under optimum operating conditions for Diesel-oil production is about half of that expected of the process when producing chiefly gasoline. The latter space-time yield is expected to be about the same as that of the fluidized iron catalyst process developed by the United States oil industry.

The slurry or liquid-phase catalyst, suspension pilot plant is shown in figure 46. Only a few preliminary operations have been made.

124/ Orchin, M., Aromatic Cyclodehydrogenation VI. Synthesis of Ring-Oxygen Compounds: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 495-497.

125/ Orchin, M., and Reggel, L., Aromatic Cyclodehydrogenation VII. Rearrangements in the Phenylnaphthalene Series: Jour. Am. Chem. Soc., vol. 70, 1948, pp. 1245-1247.

126/ Orchin, M., Reggel, L., Friedel, R. A., and Woolfolk, E. O., Aromatic Cyclodehydrogenation: Bureau of Mines Tech. Paper 708, 1948, 40 pp.

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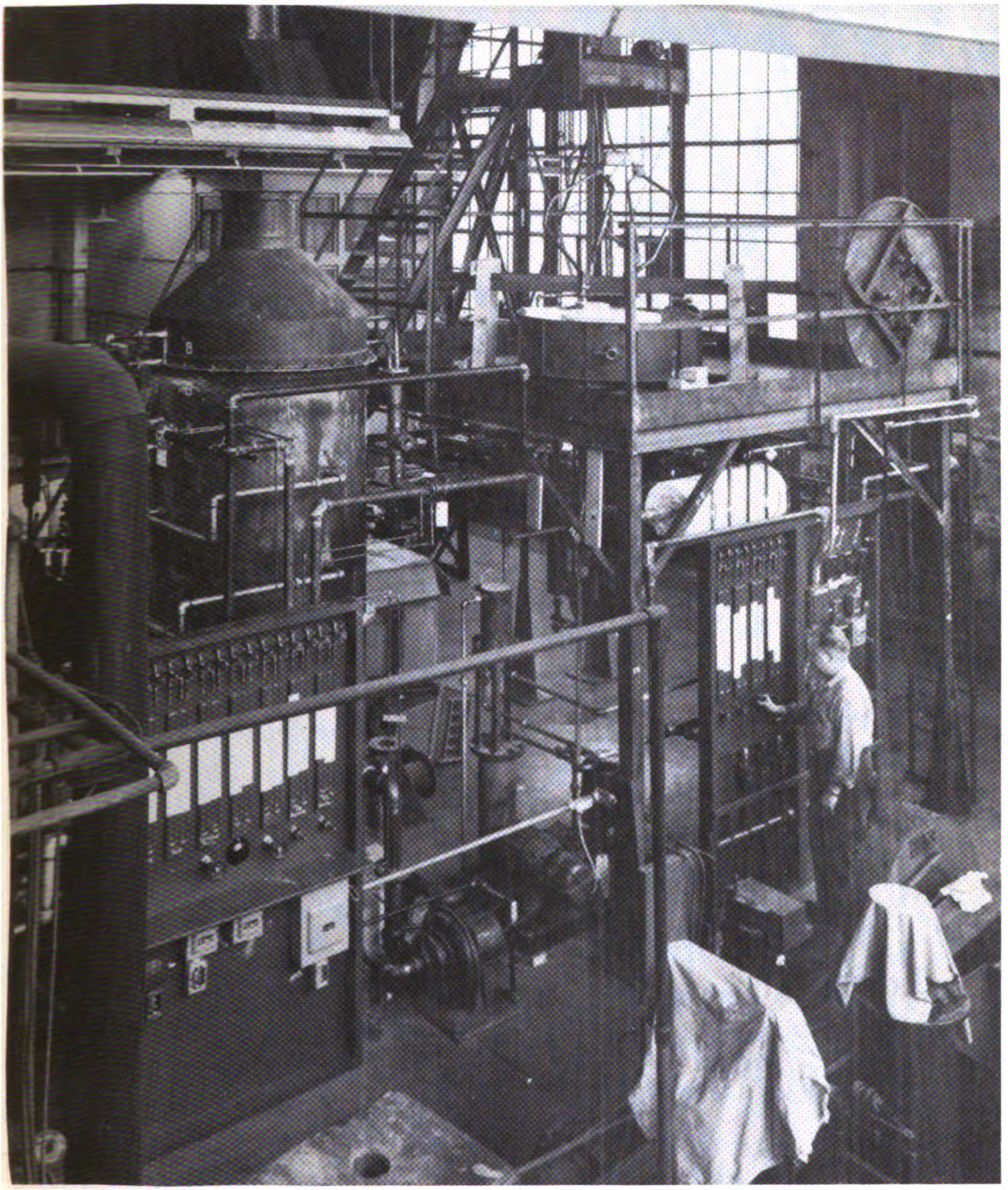

Figure 44. - Vortex powdered-coal gasification pilot plant.

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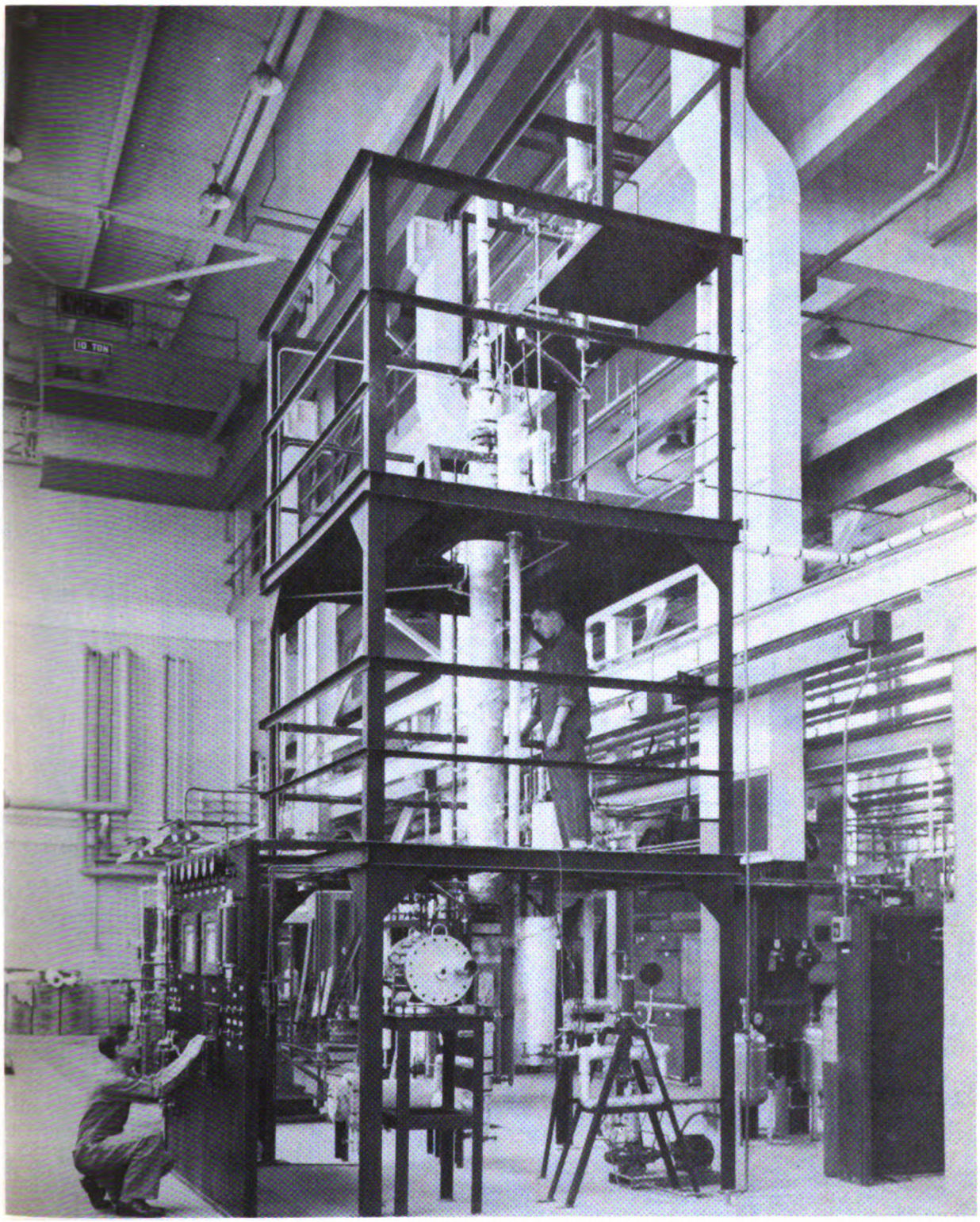

Figure 45. - Internally cooled Fischer-Tropsch pilot plant.

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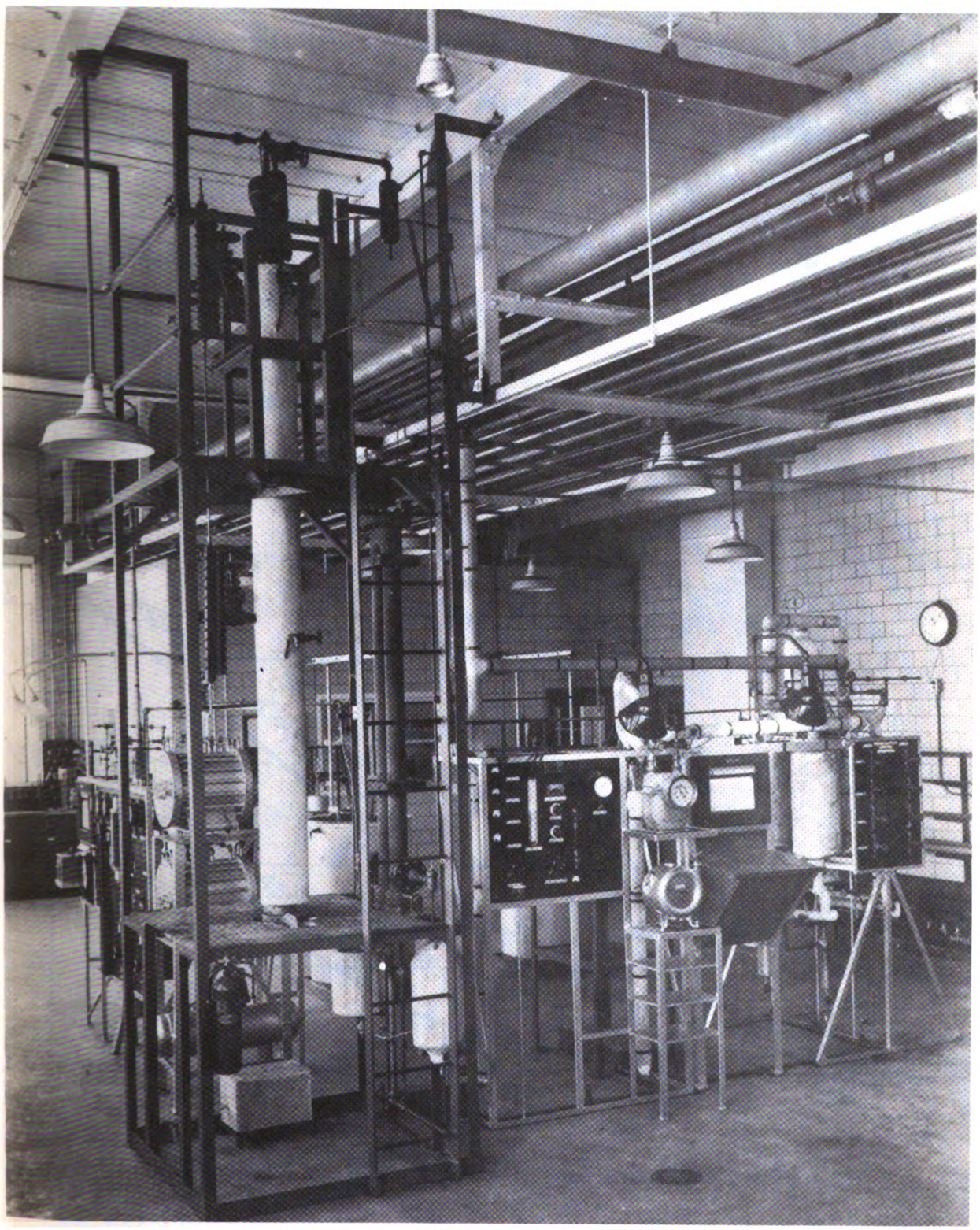

Figure 46. - Slurry-process pilot plant.

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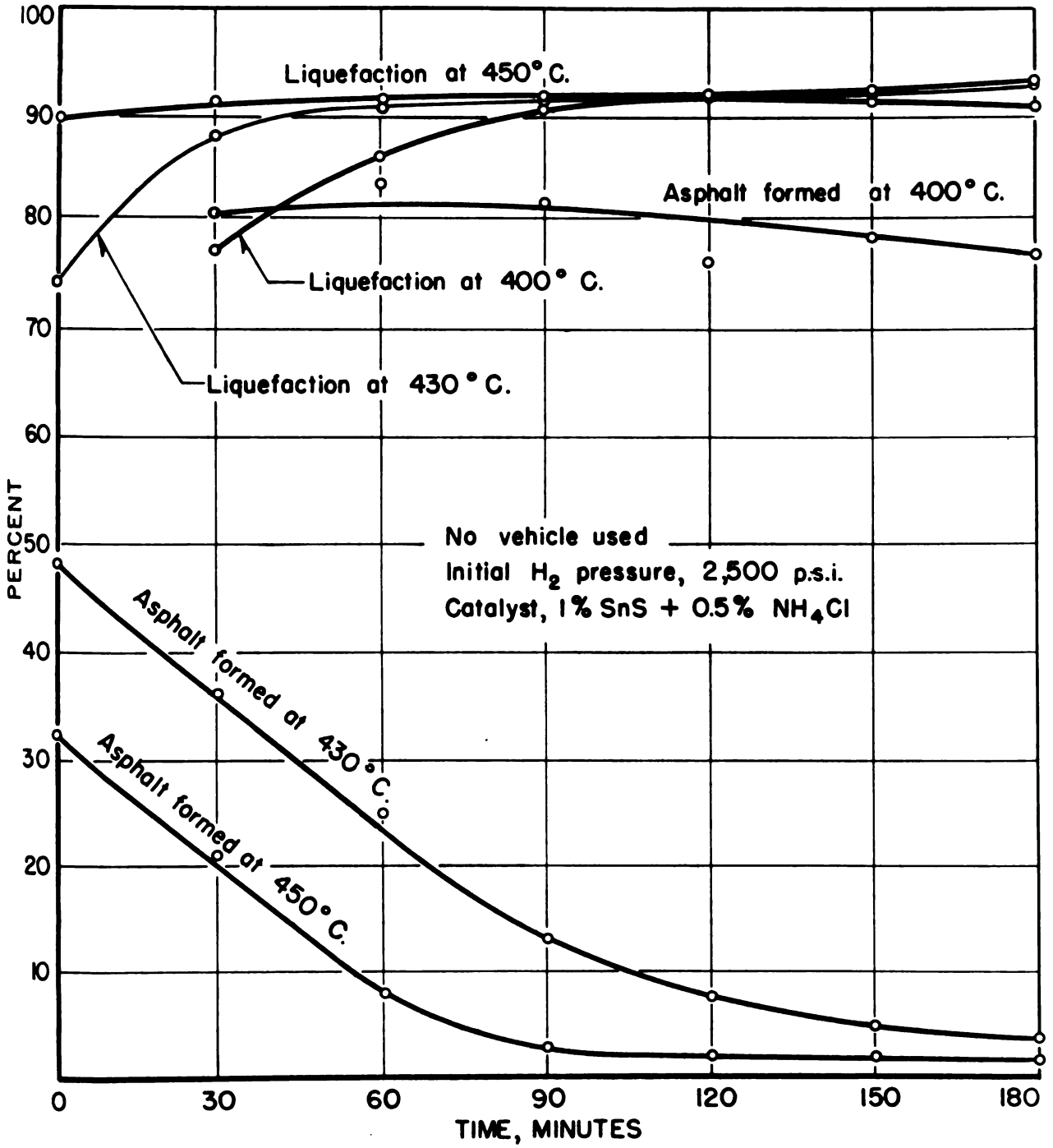

Figure 47. - Liquefaction of coal and asphalt formation.

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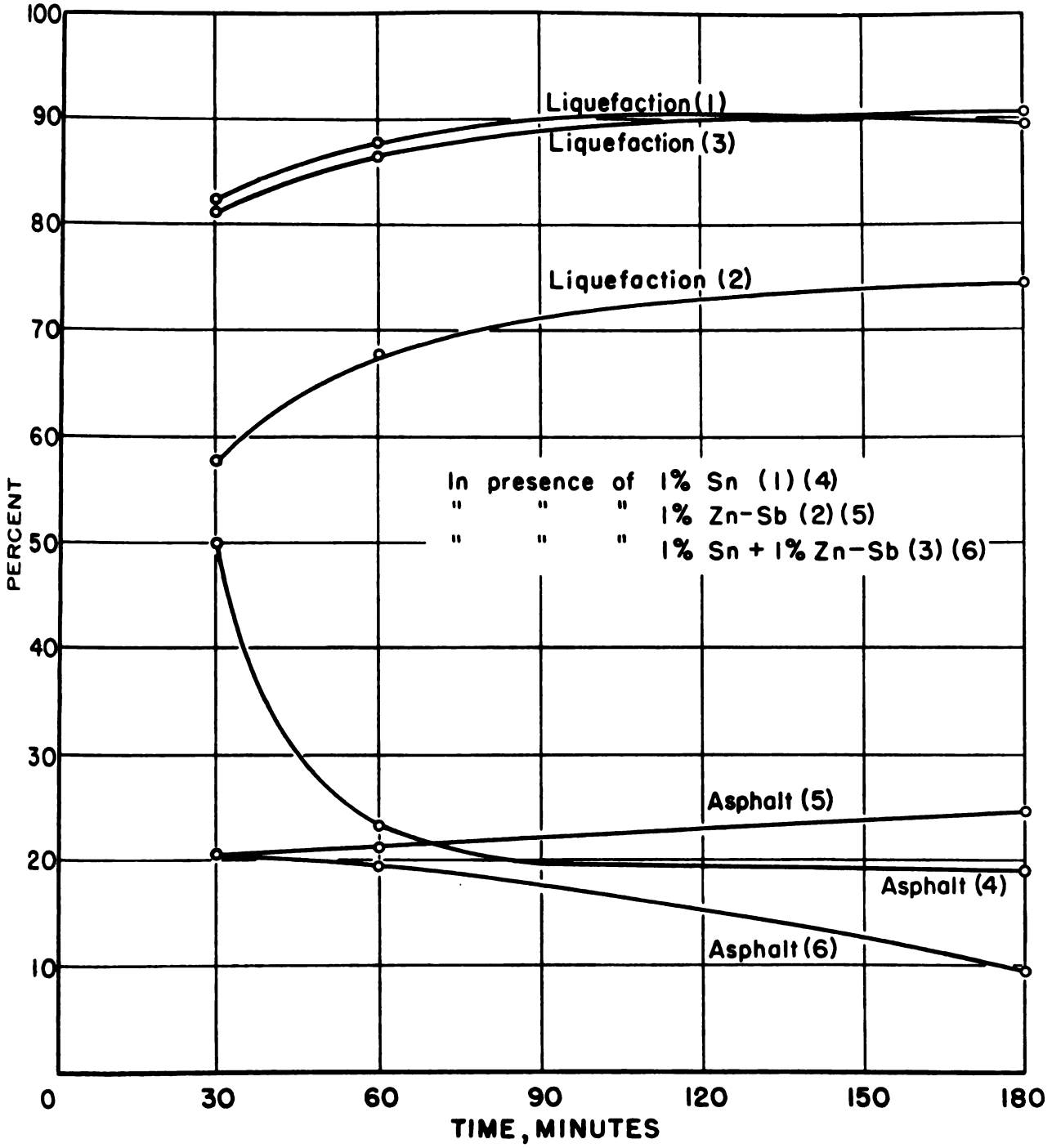

Figure 48. - Liquefaction of coal and asphalt formation at 415° C.

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Hydrogenation of Coal

Function of Solvents and Catalysts in Early Stages of Coal Hydrogenation

The absence of a vehicle or solvent does not affect the rate of liquefaction of bituminous coal, but the quantity of asphaltic material (insoluble in n-hexane but soluble in benzol) produced is much less in the absence of solvents. This observation is of importance in that the capacity of a coal-hydrogenation plant can be increased appreciably by a decrease in the amount of asphaltic material per unit of n-hexane soluble oil produced. Because of the severe engineering difficulties and high costs involved in continuous feeding of dry coal into a high-pressure plant, the immediate application of this information concerning the reduced asphalt production in dry coal hydrogenation will be made by pumping a slurry of coal and a very low boiling oil or water. Either of these vehicles can be "flashed" out of the reactor in a stream of superheated hydrogen.

In hydrogenation of coal in absence of a vehicle, the quantity of asphaltic material per unit of liquefaction decreases rapidly with increasing hydrogen pressure in the range 1,000 to 10,000 pounds per square inch, from 0.3 to 0.1. The effects of contact time and temperature[127] at 2,500 pounds per square inch initial pressure (about 5,500 pounds at reaction temperature) is shown in figure 47. At 400° C., the rate of hydrogenolysis of the asphaltic material is very low, but it increases rapidly with increasing temperature so that at 430° C. the rate is high enough for a practical coal hydrogenation process.

At low temperatures (400°-415° C.) and when a hydroaromatic compound such as tetralin is employed as a vehicle, the yield of asphaltic materials can be greatly reduced by the use of powdered zinc-antimony alloy as catalyst. This effect is illustrated in figure 48. At higher temperatures, or when either no vehicle or an aromatic hydroxylated vehicle is employed, the specificity of zinc-antimony for low asphalt production is so much less pronounced that its use in a practical coal-hydrogenation process is of little or no advantage. Similar differences have been observed in studying the relative efficiencies of tin and molybdic acid as catalysts. Thus, molybdic acid is almost as highly efficient as tin for coal hydrogenation when tetralin is used as a vehicle. When no vehicle is used, molybdic acid is markedly inferior to tin.

The outstanding efficiency of tin as a catalyst for the first stages of coal hydrogenation persists under a great variety of conditions. Whatever type of vehicle is employed, in the absence of any vehicle, and in a wide range of temperatures and pressures, tin is outstandingly more efficient than other catalysts. This is also true for a wide range in rank of coal, provided an adequate adjustment is made in the proportion of ammonium chloride used to neutralize the alkaline inorganic constituents of the coal. An excess of ammonium chloride of about 0.5 percent (of the coal) beyond the neutralization point is essential in all cases for maximum efficiency of tin. No satisfactory explanation of the unique character of tin has yet been found. Laboratory experiments designed to furnish such information are in progress.

Because of the scarcity of tin, it is necessary to employ more readily available and cheaper catalysts in practical coal hydrogenation operations. As may be seen

127/ Pelipetz, M., Kuhn, E. M., Friedman, S., and Storch, H. H., Effect of Catalysts on Hydrogenolysis of Coal: Ind. Eng. Chem., vol. 40, 1948, pp. 1259-1264.

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from table 19, when a high pressure of about 9,000 pounds per square inch of hydrogen is used, the cheaper and more readily available iron compounds approach the high efficiency of tin.

TABLE 19. - Hydrogenation of Rock Springs, Wyo., high-volatile C bituminous coal

(In laboratory autoclaves at 450° C., 3,700 pounds per square inch initial (cold) hydrogen pressure (about 9,000 pounds at reaction temperature), in absence of any vehicle. Pyrex glass liner used to avoid catalysts by metal walls.)

Run No.	Catalyst	Percent of liquefaction	Asphalt per unit of liquefaction	Percent of coal gasified
859	-	70.9	0.43	17.8
861	1 percent Sn + 0.5 percent NH_4Cl	97.7	.07	11.6
855	0.1 percent Sn as $SnCl_2.2H_2O$	87.8	.50	17.8
878	0.1 percent Sn (powdered)	82.4	.57	13.8
849	0.1 percent MoO_3	70.0	.43	16.6
881	0.1 percent Zn + 0.2 percent NH_4Cl ..	75.6	-	-
857	0.1 percent Fe as $FeSO_4.7H_2O$	70.6	.51	15.6
866	1 percent Fe as $FeSO_4.7H_2O$	84.7	.55	13.5
872	1 percent Fe (powdered)	64.7	.61	11.6
875	1 percent Fe as pyrite	83.1	.43	13.5
845	1 percent dried "red mud"1/	83.5	.49	19.1

1/ Obtained through the courtesy of the Aluminum Co. of America. This material is the equivalent of Bayermasse, used extensively in German coal-hydrogenation plants.

The uncatalyzed hydrogenation resulted in a liquefaction of 71 percent. As usual, Sn (in the presence of Cl) proved to be outstanding. The "Standard" catalyst, 1 percent Sn + 0.5 percent NH_4Cl, produced a liquefaction of 98 percent. 0.1 percent Sn, added as $SnCl_2$, resulted in 88 percent liquefaction, while 0.1 percent Sn powder was somewhat less effective. At a concentration of 0.1 percent, all other catalysts tried were relatively poor. Since it is desired to use an iron catalyst in the demonstration plant if possible, several iron catalysts were tested at a higher concentration level. Of these, dried "red mud"128/ seems most promising. At a total concentration of 1 percent, it is as effective as 1 percent iron in the form of $FeSO_4$ (that is, 2.7 percent $FeSO_4$), and it is probably considerably cheaper.

The extent of gasification varied in a random manner in these experiments, and it did not seem to be associated with the extent of liquefaction. The asphalt production was high in all cases except that in which 1 percent Sn was used.

Laboratory-Scale Process Development

A reactor for studying the hydrogenation of dry coal has been built. Experiments will be made in a wide range of temperatures, pressures, and catalysts. The apparatus, which is shown in figure 49, is arranged so that a continuous feed of powdered coal is supplied from a pressurized hopper, and a continuous stream of preheated hydrogen keeps the powdered coal in suspension. The volatile reaction products are carried out in the stream of hydrogen gas and the nonvolatiles discharged as a heavy pitch or slurry of unreacted coal and ash in a heavy oil.

Early experiments indicate that valuable process design information can be obtained from this unit.

128/ See footnote 1, table 19.

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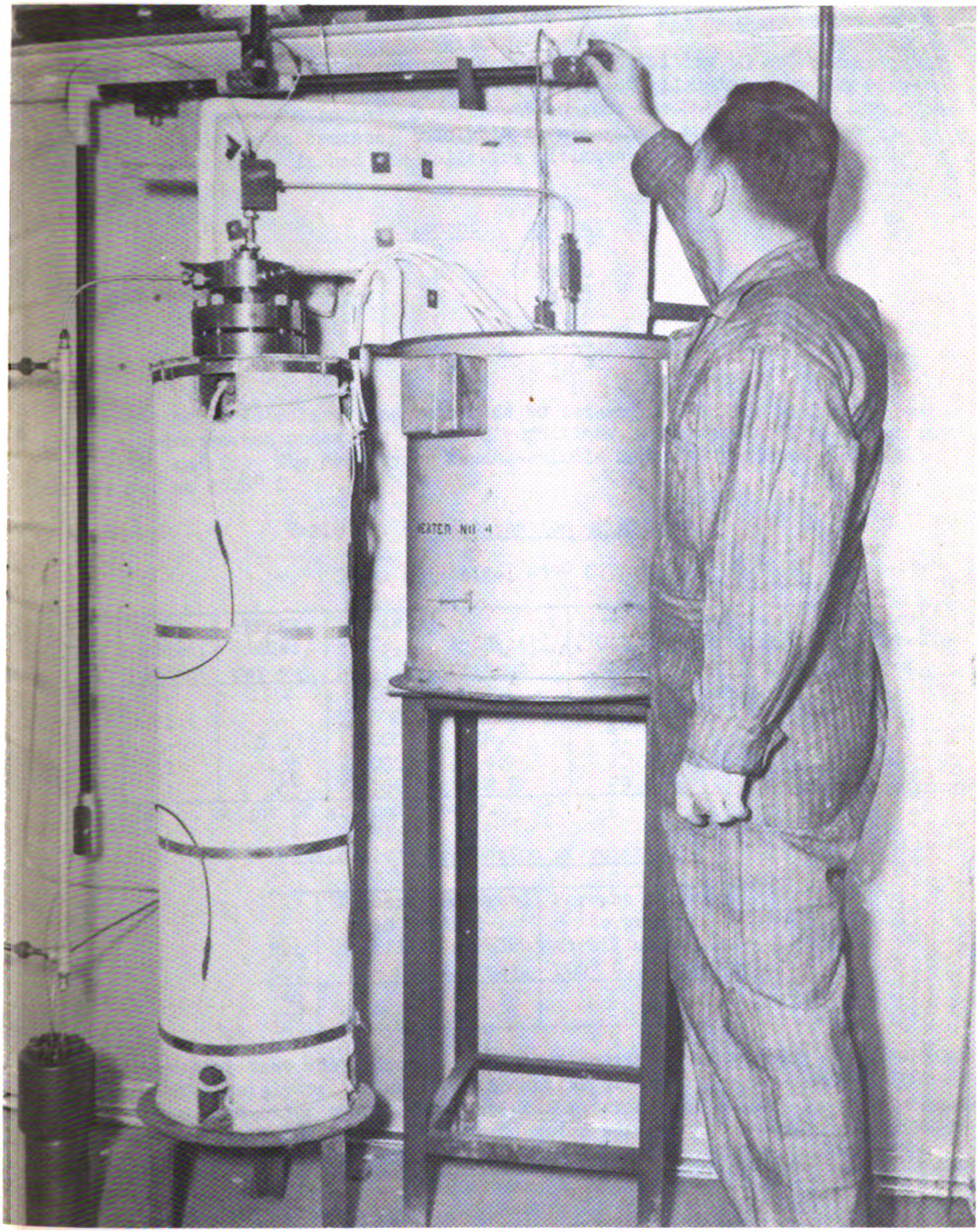

Figure 49. - Laboratory reactor for coal hydrogenation in absence of vehicle.

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Because of widespread interest, a description of the bench-scale coal-hydrogenation equipment and procedures has been published.129/

Interest was expressed in determining the susceptibility to hydrogenation of gilsonite, a naturally occurring asphalt. A sample of gilsonite from the Uinta Basin, Utah, was found to contain 2.0 percent benzene-insoluble material, 79.0 percent asphalt (soluble in benzene, insoluble in n-hexane), and 19.0 percent oil (soluble in n-hexane). It had the following ultimate analysis:

Element	Weight, percent
H	10.13
C	85.16
N	3.18
O	1.18
S	0.26
ash	0.09

Several batch autoclave runs were made to determine the ease with which gilsonite is hydrogenated under our standard conditions. The results are summarized in tables 20 and 21. The density of hexane-soluble material produced was 0.911 gram per cc. at 25.6° C.

TABLE 20. - Hydrogenation of gilsonite

50 g. gilsonite, 450° C., 1 hr.

Run No.	Sn added, percent	NH_4Cl added, percent	Initial pH_2, p.s.i.g.	Asphalt,1/ percent	Oil,1/ percent	Gasification,1/ percent	Benzene insolubles,1/ percent
762	-	-	1,000	14.2	61.0	14.2	11.4
749	1	-	1,000	17.6	56.8	17.4	9.2
750	-	0.55	1,000	16.8	51.8	19.8	13.6
726	1	.55	1,000	4.0	79.2	15.2	4.7
739	1	.55	1,500	2.2	79.8	17.6	2.9

1/ Based on weight of gilsonite only.

TABLE 21. - Production of volatile oil

Run No.	Percent converted to product distillable below 85° C., 1 atmos.	Percent converted to product distillable below 200° C., 2 mm. Hg
726	28.6	60.6
739	32.0	65.2

It is evident that the hydrogenation of gilsonite proceeds with ease, even in the absence of a catalyst. Unless both Sn and NH_4Cl are present, however, there is an appreciable production of benzene-insoluble material and a decrease in the quantity of asphalt converted to oil. Gas production was about the same in all the experiments. As may be seen from table 21, about 30 percent of the gilsonite is

129/ Clark, E. L., Golden, P. L., Whitehouse, A. M., and Storch, H. H., Bench-Scale Equipment and Techniques - High-Pressure Reactions: Ind. Eng. Chem., vol. 39, 1947, pp. 1555-1564.

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easily convertible to very volatile product, and up to 65 percent is converted to oil distillable below 200° C. at 2 mm. Hg (for an initial H_2 pressure of 1,500 p.s.i.g.). From this point of view, gilsonite would seem to be an excellent source of liquid fuels; unfortunately, the total reserves of gilsonite amount to only about 0.5 percent of the annual production of petroleum in the United States.

Analyses were made for carbon and hydrogen on the benzene-insoluble asphalt and oil products from various runs, and the results are listed in table 22.

TABLE 22. - Ultimate analyses on products

Run No.	Nature of product	Carbon, percent	Hydrogen, percent	Cl, percent
749	Benzene-insoluble	75.00	4.22	-
	Asphalt	85.03	7.19	-
	Oil	85.71	11.86	-
750	Benzene-insoluble	83.46	4.31	0.89
	Asphalt	86.27	7.48	.07
	Oil	86.57	11.46	.04

The low percentage of carbon for the benzene insolubles of run 749 is due to the ash (Sn) content. In general, the carbon and hydrogen contents of the three fractions are those which might be expected from the solubility characteristics. Of interest is the low Cl content of the oil and asphalt from run 750, in which only NH_4Cl was added as catalyst. This indicates that although NH_4Cl (or HCl) may act to split asphalt, at least in the case of gilsonite, only a very small quantity of Cl, at most, is chemically bound with the soluble products after hydrogenation. The Cl found in the benzene-insoluble product from run 750 is equivalent to only one-third of the Cl added as NH_4Cl, and it is almost exactly equivalent to the ash (taken as CaO) present in the original gilsonite.

Pilot-Plant-Scale Experimentation

The pilot plants, one for the first or liquid-phase stage and one for catalyst testing in the second or vapor-phase stage are being completed. Some views of the liquid-phase plant are shown in figure 50, hydrogen compressor valve, manifold (fig. 51) view of high-pressure liquid and paste pumps (fig. 52), liquid-phase reactors (fig. 53), feed and product control valves, and off-gas scrubbers for ammonia, hydrogen sulfide and hydrocarbons.

A series of runs was completed on production of heavy fuel oil in the liquid-phase coal hydrogenation plant. A mathematical analysis of the sampling problem in plants such as the coal hydrogenation pilot plant was made.130/

Demonstration-Plant Construction

Under construction at the Missouri Ordnance Works site at Louisiana, Mo., is a 200- to 300-bbl.-per-day Coal-Hydrogenation Demonstration Plant. Architectural and engineering-design work and 98 percent of the construction are completed.

130/ Kandiner, H. J., Sampling Lag and Purging Time in Mixing Vessels in Series: Chem. Eng. Progress, vol. 44, 1948, pp. 383-386.

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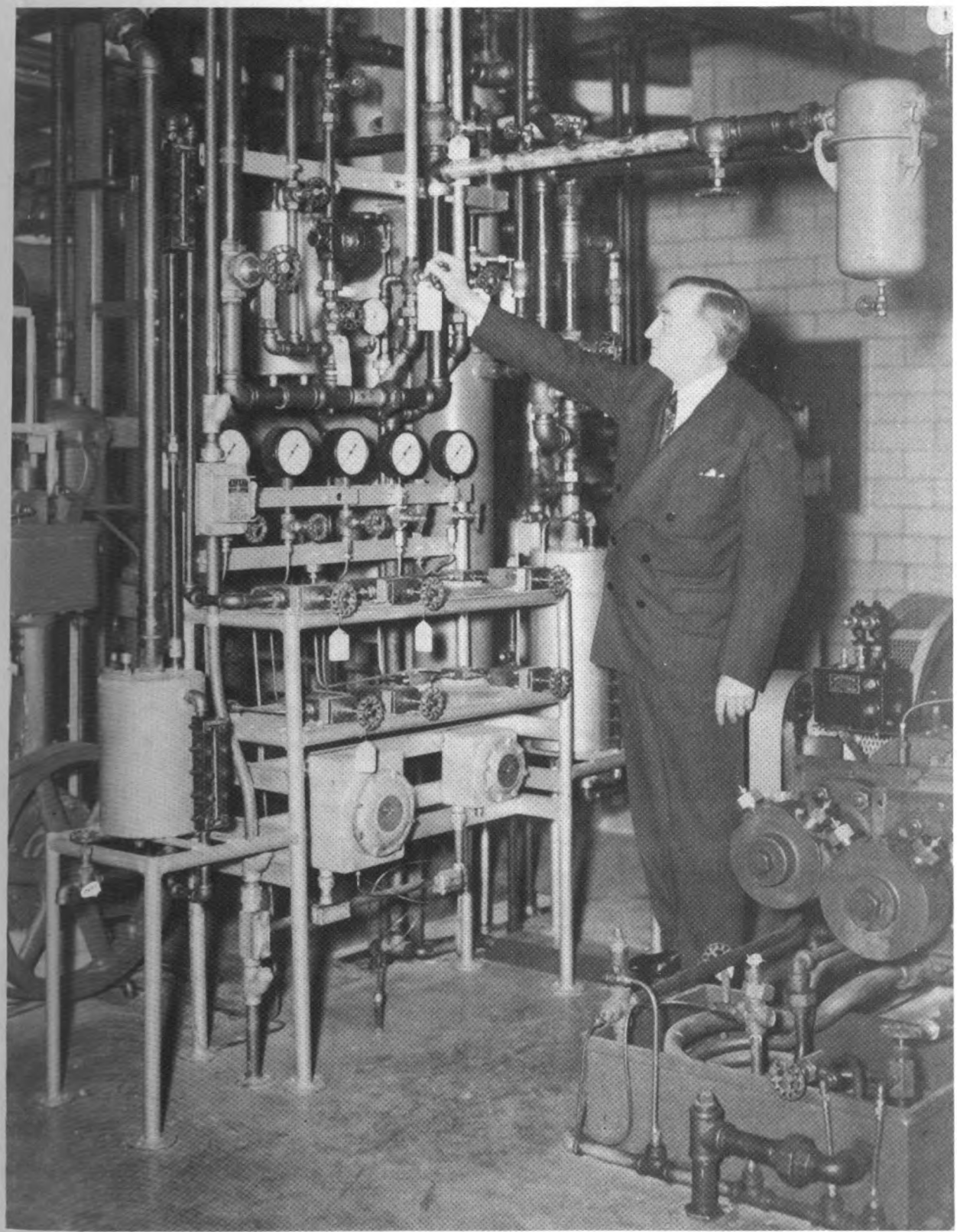

Figure 50. - Hydrogen compressor-valve manifold.

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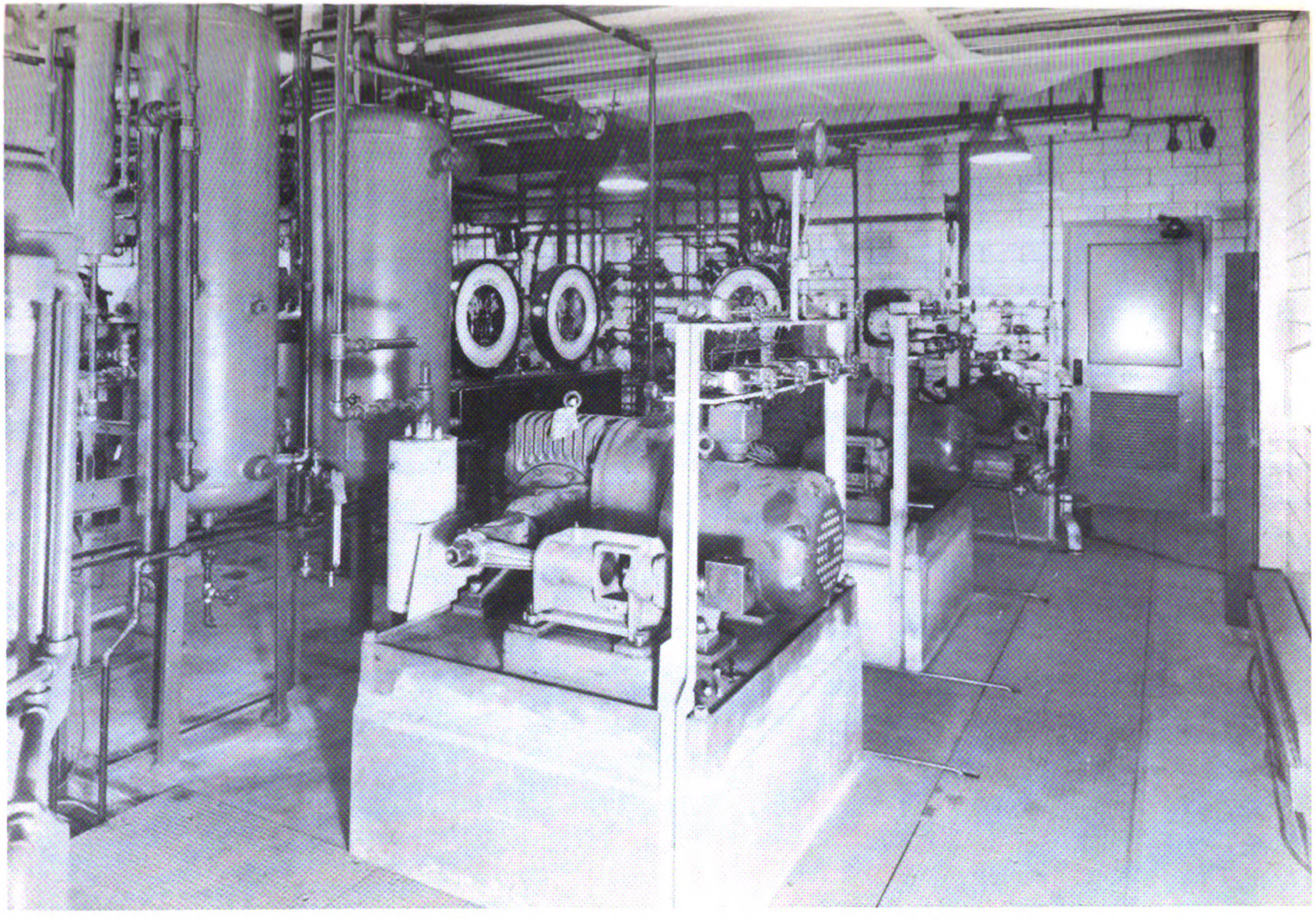

Figure 51. - High-pressure liquid and coal-paste pumps.

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Figure 52. - Liquid-phase coal-hydrogenation reactors.

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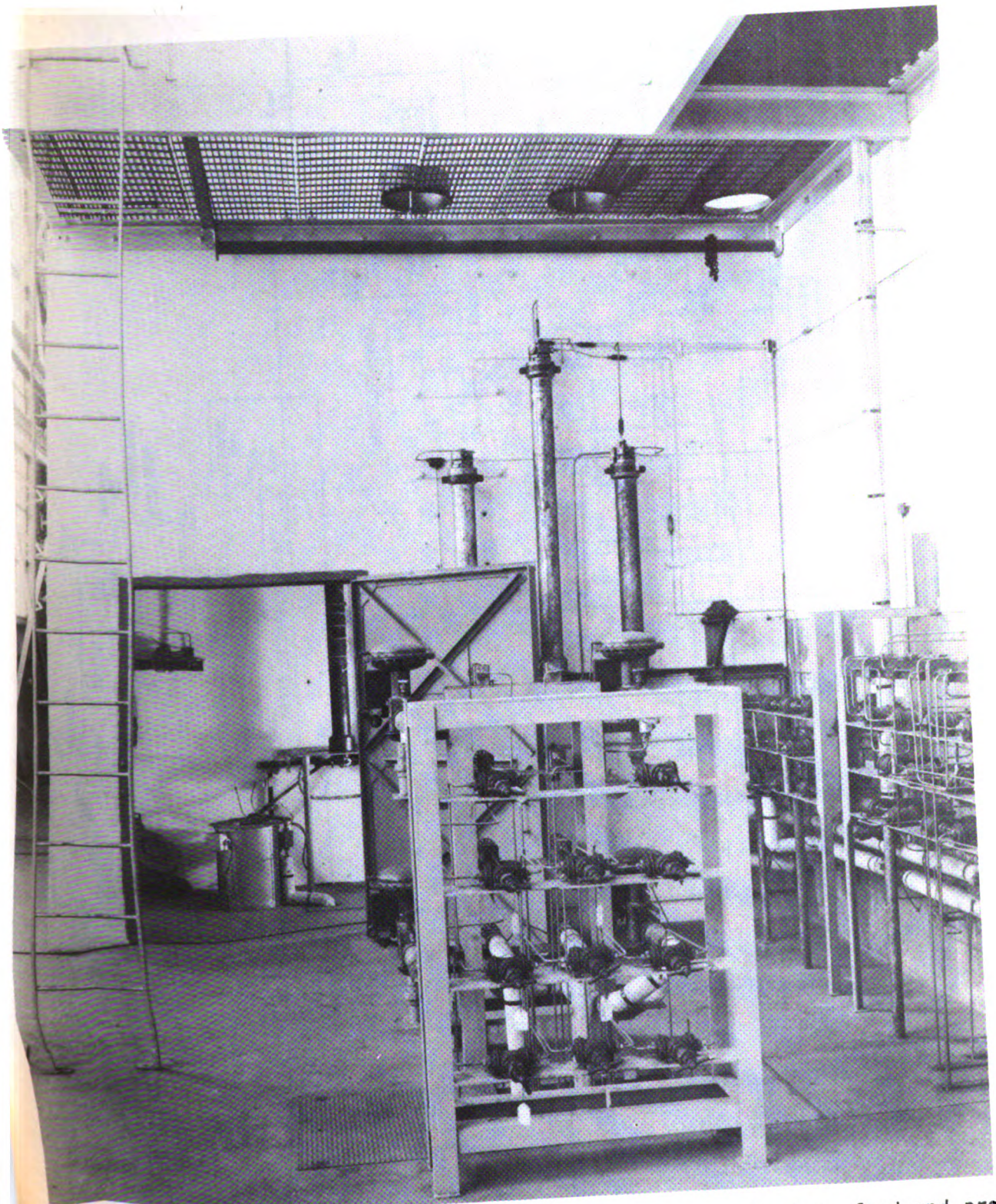

igure 53. - Coal-hydrogenation liquid-phase plant, showing preheater, feed and produc
control valves, and off-gas scrubbing vessels.

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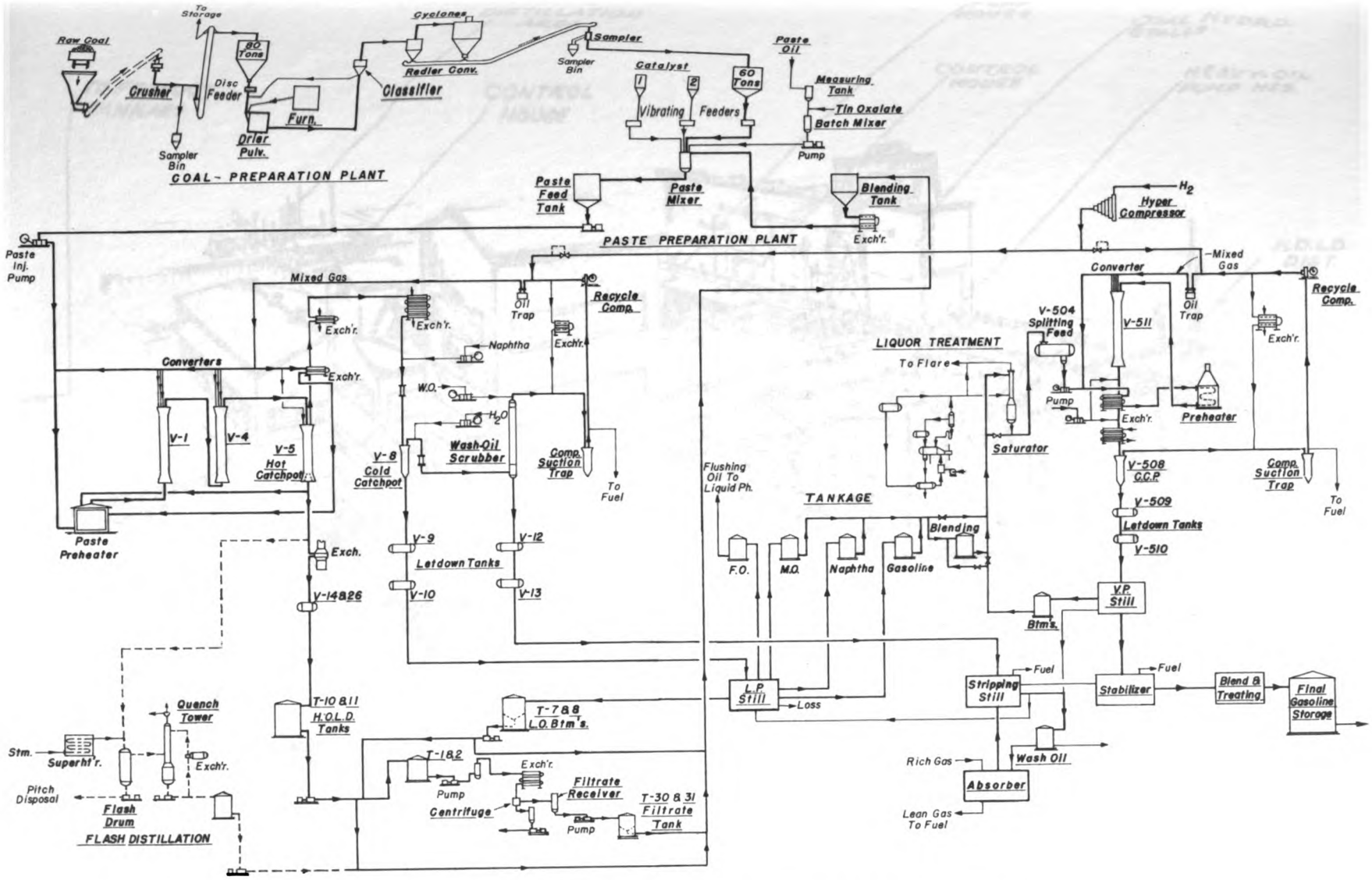

Figure 54. - Coal-hydrogenation process flow diagram.

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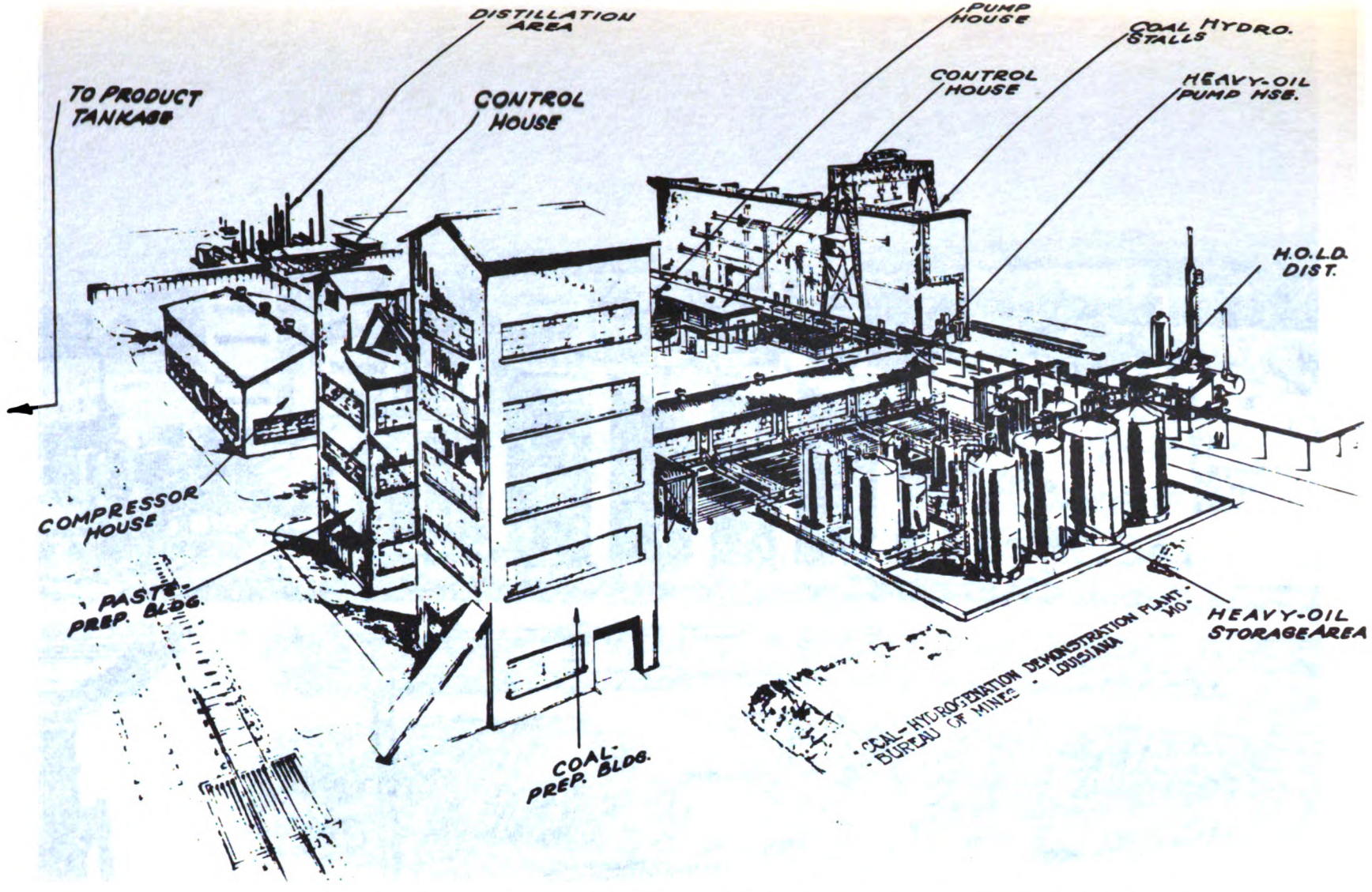

Figure 55. - Sketch of Bureau of Mines Coal-Hydrogenation Demonstration Plant at Louisiana, Mo.

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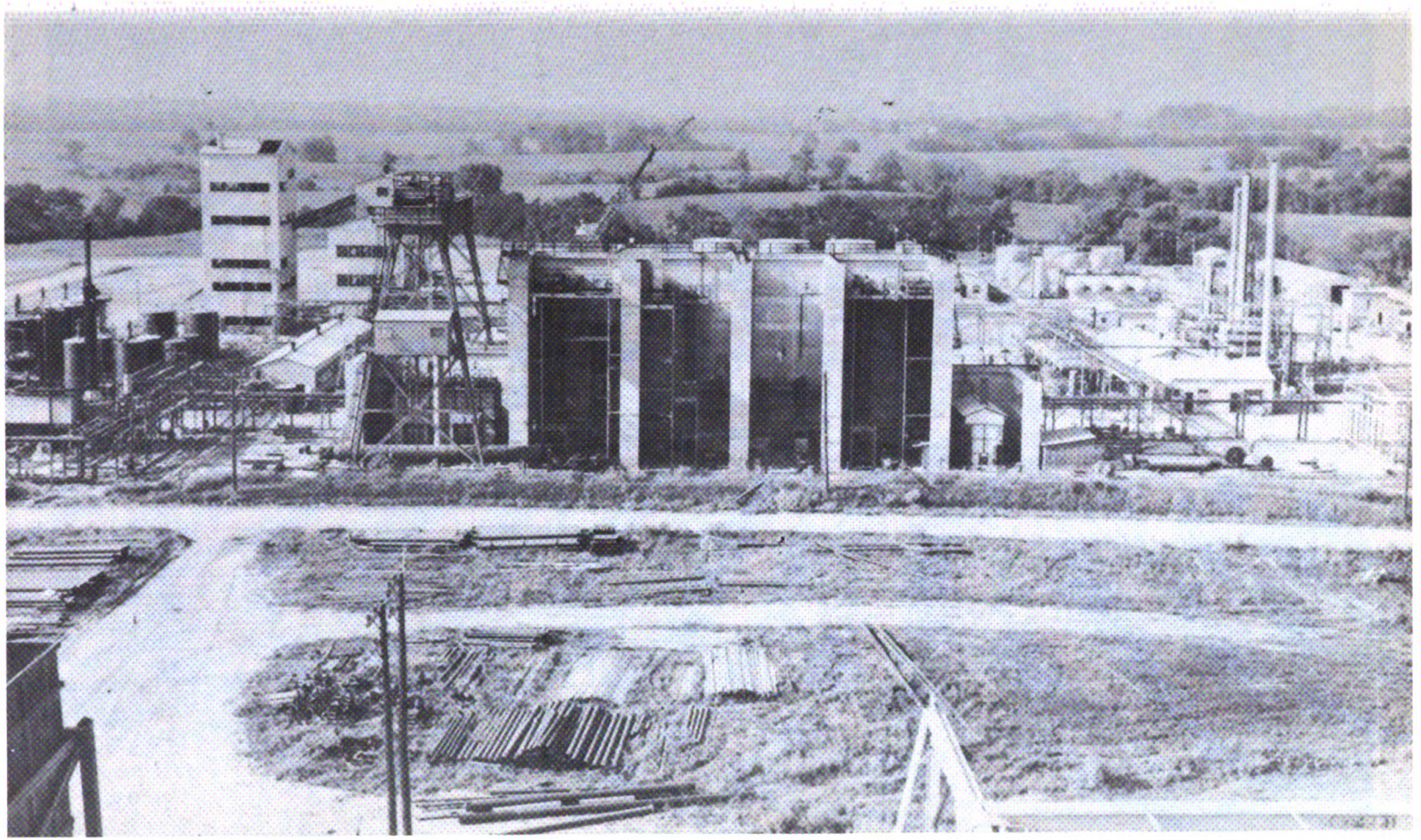

Figure 56. - General view of liquid- and vapor-phase converter stalls.

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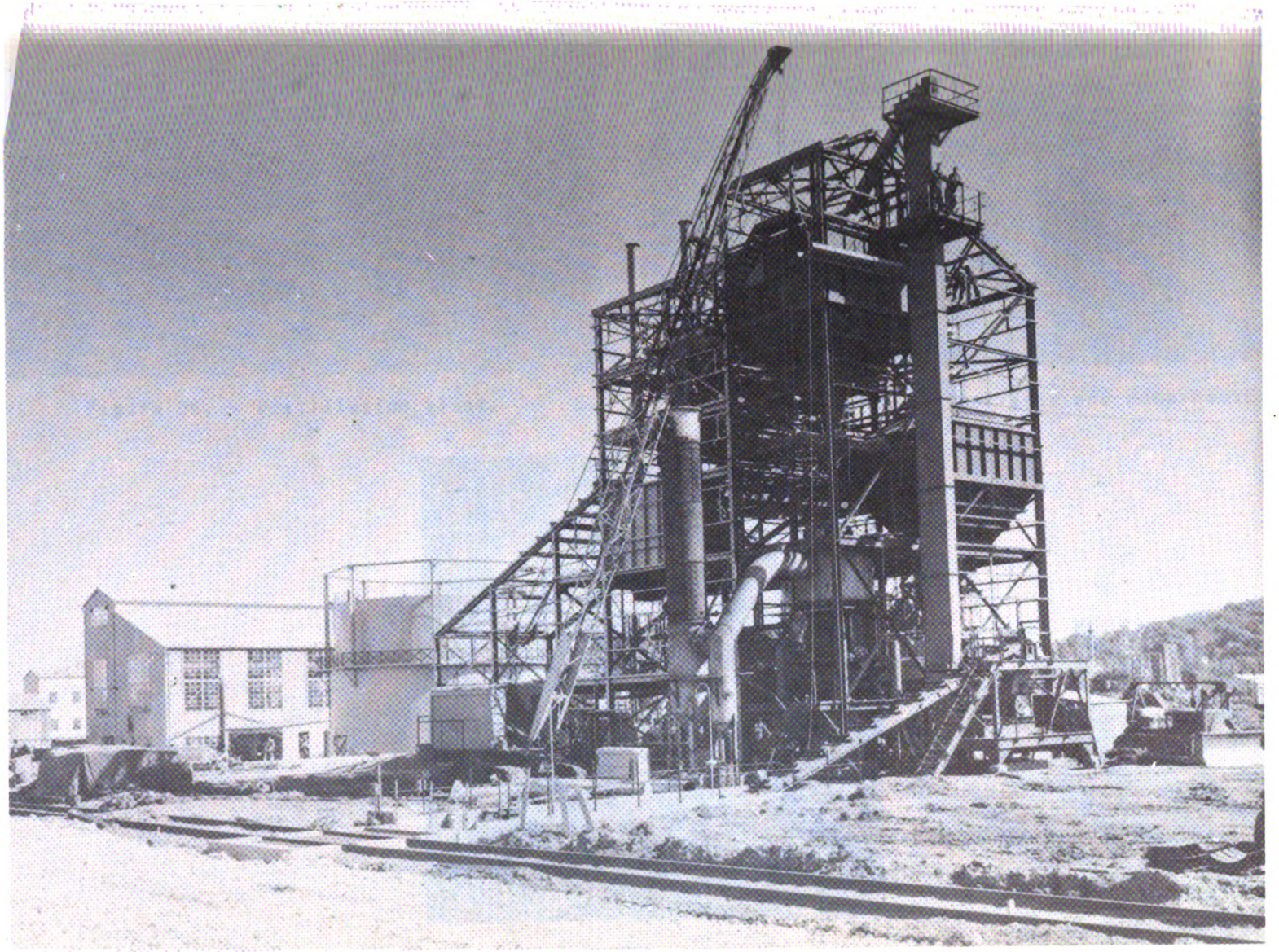

Figure 57. - Coal-gasification building under construction; oxygen building and holder in left background.

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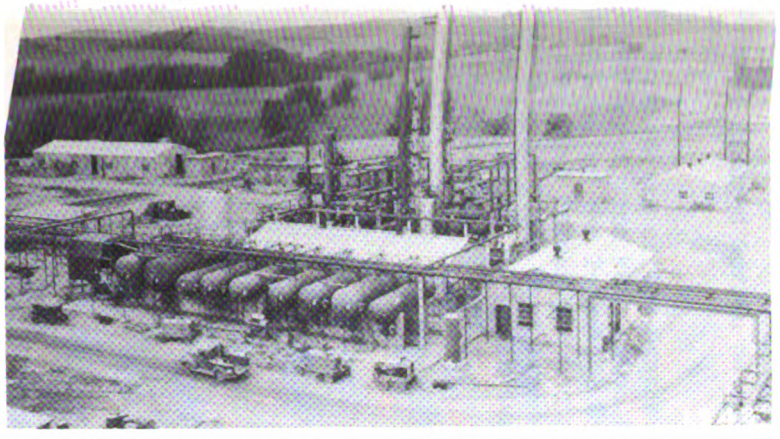

Figure 58. - Distillation plant.

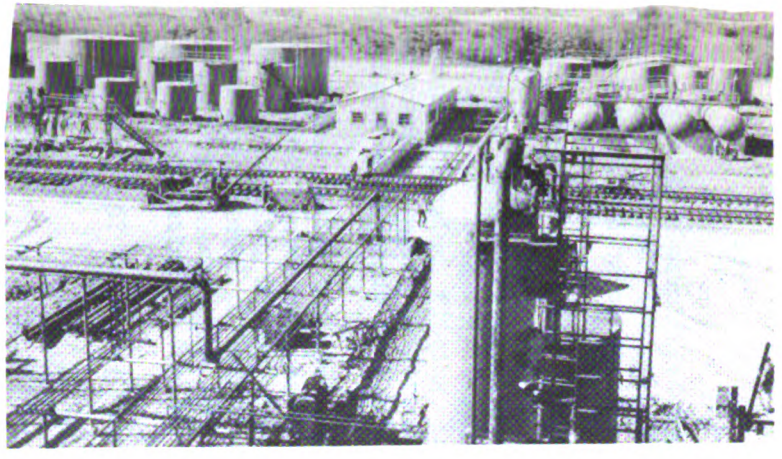

Figure 59. - Storage-tank area and pump house.

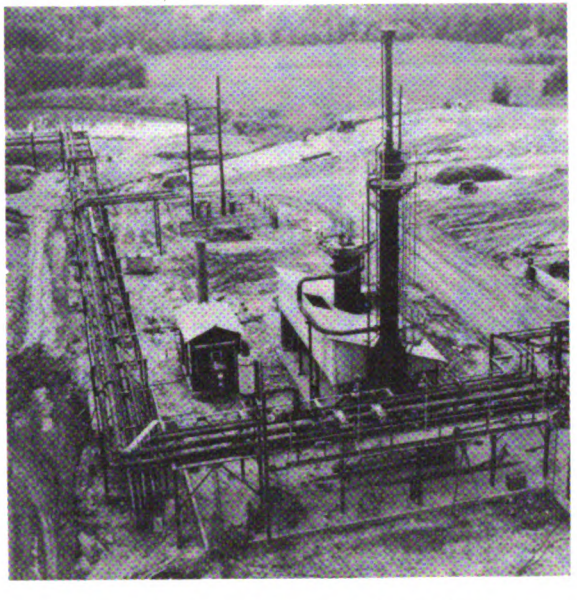

Figure 60. - Heavy-oil let-down flash distillation.

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Figure 54 is a simplified process flow diagram of the Coal-Hydrogenation Plant; figure 55 is a perspective sketch of the whole plant; and figure 56 is a general view of liquid- and vapor-phase converter stalls.

Hydrogenation will take place at 700 atmospheres pressure in two major steps: Liquid-phase hydrogenation or liquefaction of coal, and vapor-phase hydrogenation or conversion of the liquefied coal to L.P.G. gasoline and Diesel oil.

Tubing, flanging, fitting, and valving standards were set up for 10,300 p.s.i. working pressure, using different materials for three different temperature groups, ranging from atmospheric to 1,000° F.

Equipment design involved 10,000-p.s.i. pumps, heat exchangers, fired preheaters, and forged converters; and Bureau of Mines engineers brought manufacturers up to date on prevailing Germany practices. Numerous improvements were worked in above the German level of technology such as the superheated steam jacketed paste preheater, added instrumentation regulating liquid levels, flows and pressure drops, and flash distillation of the heavy oil letdown with superheated steam.

The figures 57 through 60 show the plant in the final stages of construction.

Technical Reports and Foreign Document Work

Exhaustive literature and patent surveys on synthetic-liquid-fuel processes have been continued.

Several hundred German patents and applications were received, reviewed, and translated.

The activities of the Synthetic-Liquid-Fuels Foreign Documents Division have been transferred from Washington to Pittsburgh. During the past year, microfilming and collecting of the Technical Oil Mission documents, study reports and translations of captured German documents and papers of the German scientists relating to synthetic liquid fuels have been continued. Files of the above material are being maintained, enlarged, and made available to the general public and to the fuels industry as a reference library.

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